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MECHANICAL OVERHAUL PROCEDURES FOR HYDROELECTRIC UNITS

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MECHANICAL OVERHAUL PROCEDURES FOR HYDROELECTRIC UNITS

I. INTRODUCTION

Periodically, all hydroelectric generators require a major overhaul. The extent of the work required during an overhaul will depend a great deal on operating conditions such as water quality and how the unit was loaded. In order for the overhaul to proceed smoothly and to accomplish all the work required, planning should start well before the overhaul starts.

II PREPARATION

2.1 Maintenance records

One of the best sources of information in planning a major overhaul should be the maintenance records for the unit or units involved. These records should provide details on the history, present condition, and any unusual maintenance problems of the unit. This can help identify specific items that may need attention during the overhaul. Reports of previous overhauls can prevent the same mistake from being made twice and may provide tips that can expedite the overhaul procedure. The maintenance files may also provide names of sources for parts and materials.

2.2 Inspection

At least 6 months, but preferably a year before the planned overhaul, a thorough inspection of the unit should be made to determine the condition of the equipment. Any items that will require maintenance or replacement should be documented. Many times, due to power or water delivery constraints, the amount of time allowed for the unit inspection may be very limited. Because of this, any item that can be inspected or checked without a full clearance should be taken care of prior to, or following, the outage for the main inspection. This will allow more time for a thorough inspection of the other items.

The inspection should include, but not be limited, to the following items:

Turbine runner. Unwater the unit and install draft tube scaffolding to allow the inspection of the underside of the runner. Check each bucket carefully for cavitation damage and cracks. If possible, use die penetrant or other nondestructive test to check for cracks. Compare seal ring clearance readings with design 'clearances. Open wicket gates to full open to allow inspection of inlet area of runner. Again look for cavitation damage and cracks.

Draft tube. Check condition of coating on draft tube liner' Look for any cavitation damage, especially directly under the turbine runner on the throat ring. Tap draft tube liner with a hammer to find any voids that will require grouting.

Spiral case and penstock. Check condition of interior coating and exterior coating of exposed portions of penstock. Pay special attention to the exterior of the penstock where it emerges from concrete.

Wicket gates. With gates open, inspect each gate, checking the condition of the seal area, the surface coating, and for any cavitation damage. If sealing surfaces are uneven or damaged, they should be repaired by welding and machining back to drawing dimensions. With the gates closed, check the top and bottom clearances between - the gates and the facing plates and the clearances between the gates. The heel and toe sides of the gate should both be measured when checking the top and bottom clearances. In checking the clearances between gates, check the clearance at the top, middle, and bottom. Check condition of facing plates looking for any galling or wear from contact with the wicket gates. If the facing plates are severely damaged, they will require replacement or resurfacing.

Wicket gate operating linkage. Move gates through their full range of movement in both directions several times. Watch for any lateral movement of the shift ring or backlash in the wicket gate linkage. Remove the gate arm from one wicket gate and inspect thrust washer. Check wicket gate bushing clearance by jacking wicket gate shaft and measuring movement with dial indicators. This may not give a true indication of clearance due to hardened grease or other debris in the bushings. Check servomotor shaft for scoring. If possible, remove servomotor cylinder head and check cylinder bore for scoring.

Bearings. Check condition and dimensions of all spare guide and thrust bearings. Have bearings rebabbitted if necessary.

Generator rotor. Thoroughly inspect all stress carrying parts of rotor for cracks. Pay particular attention to welds on the rotor spider.

Generator air coolers. Check for any leaks. If possible, inspect interior of tubes for scale buildup or corrosion. If spare coolers are available, make sure they are ready for installation.

2.3 Drawings

Several sets of manufacturer's "as-built" drawings should be obtained for both the generator and turbine. Prior to the overhaul, the overhaul supervisors should study the drawings and become familiar with the

construction of the machine. Any special instructions on any of the drawings for disassembly or reassembly should be noted. Any special tools listed in the drawings should be located, or if not onsite, purchased or fabricated.

A list of weights of all of the machine's components should be made from the drawing information. If the weights are not listed on the drawing, approximate weights must be calculated. This list is essential in determining what rigging will be required for the overhaul.

Drawings of the powerplant should also be studied to determine where the major components from the unit can be stored. The space available and the allowable floor loading must be taken into account. It may be necessary to store some parts outside of the plant. If this is required, some provision must be made to protect these parts from the elements.

2.4 Lifting devices and rigging

All of the rigging that will be required during the overhaul, such as slings, eyebolts, and shackles, should be on hand well before the overhaul is to begin. The required rigging for each component should be determined based on the list of weights. Rigging already onsite should be inspected to make sure it is safe for use. Special lifting devices supplied by the manufacturer, such as for the generator rotor or turbine shaft, should be located and inspected. Dynamometers or crane scales can be very helpful during an overhaul. A calibrated dynamometer can tell how much weight is being lifted during a single point lift or how much weight one leg of a multileg sling is lifting. This can prevent overloading the rigging when lifting parts that may be stuck, such as the turbine headcover, or when some of the fasteners have been accidently left in place. If a dynamometer is already onsite, it should be calibrated before the overhaul begins.

Sending personnel who will be involved with the rigging to a rigging class should be considered. These classes provide training in proper rigging procedures, inspection of cranes and rigging equipment, and proper operating procedures for cranes.

A set of two-way radios can be very helpful in communicating with the crane operator. Voice-activated, headset-type radios keep hands free to allow the signaler to make hand signals and the crane operator to keep his hands on the controls.

A careful inspection of the powerplant crane should also be accomplished before the overhaul. Consideration should be given to hiring a consultant, experienced in crane inspections, to check out the crane and provide recommendations. Besides inspecting the wire rope, brakes, hooks, hoist motors, and gear boxes, operational tests should be performed. It is very

important that bridge, trolley, and hoist can be "jogged" to allow precise positioning of the load. **Any problems or deficiencies with the crane must be corrected before the overhaul is started.**

Many times it is helpful to fabricate special lifting devices or install a trolley track to facilitate disassembly. Any shop-fabricated lifting device or fixture must be designed and certified by an engineer qualified in this field and tested at 125 percent of the rated safe working load. All lifting devices and rigging hardware must be designed with a safety factor of no less than 5:1 based on the tensile strength of the materials of construction.

2.5 Scheduling

Supervisors, craft personnel, and engineers should meet to discuss what work will be required during the overhaul so that the schedule can be optimized. A critical path flowchart can be very helpful in scheduling an overhaul. Typically, the flowchart shows the order in which various tasks must take place, the time required for each task, and which tasks can be accomplished concurrently. There are a number of "critical path method" software packages for personal computers available to assist in setting up a flowchart. This software allows the schedule to be easily adjusted when unexpected delays occur. Many of these packages will also allow manipulation of the schedule based on available personnel.

In setting up the schedule for a major overhaul, it is important to be realistic and possibly a little pessimistic in regard to what work will have to be done and how quickly it can be accomplished. On the first unit to be overhauled, extra time should be allowed for unexpected problems.

A checklist should also be maintained to make sure all tasks are completed and to record when they were completed. - As the overhaul progresses, the list should be modified to include any items missed on the original list or remove any items not required. The checklist should include any testing or adjustments that will be required before the units are started or released for operation.

2.6 Hydraulic transient study

If the unit is being uprated, it is likely that the closure rate for the wicket gates will have to be changed to prevent overpressuring the penstock following a load rejection. To determine what the new wicket gate timing should be, a water hammer or hydraulic transient study should be performed with the new parameters for the uprated unit. If the overhaul is not an uprate, the original test data or records showing the recommended wicket gate timing should be located. If this information is not available, a hydraulic transient study should be performed. In the case of an uprate or lost test data, load rejection tests must be performed following the overhaul to verify the results of the hydraulic transient study.

2.7 Procurement of equipment and supplies

Based on the inspection of the unit and on the discussions during the scheduling meeting, a list of required materials, tools, and services should be made. Specifications for materials and tools required for the overhaul should be prepared as well as "Statements of Work" for contract services. If it is not certain whether contract service will be required, the "Statement of Work" should be prepared so it can quickly be issued once it is confirmed that it will be required.

Do not wait until the overhaul is in progress to order parts. Some parts, because they are unusual or in short supply, may require several months lead time to procure.

The following is a list of suggested materials and tools to have on hand for a overhaul:

Wicket gate bushings, thrust washers, linkage bushings, and shift ring bearing pads. At least one full set of wicket gate bushings, thrust washers, linkage bushings, and shift ring bearing pads should be procured and onsite prior to the overhaul. The wicket gate bushings should have an undersized inner diameter to allow inplace line boring. If the spare bushings supplied with the turbine do not have an undersized inner diameter, another set of bushings should be ordered. A bearing bronze such as UNS C93200 should be specified.

There are several types of greaseless or self-lubricated bushings available from various manufacturers for use in wicket gate applications. Each type has its own application and installation requirements. Conduct extensive research before switching to selflubricated bushings. Remember, if a wicket gate bushing fails in service, in most cases the entire unit must be disassembled to make repairs. Contact facilities that have installed the type of bushing being considered to get an account of their experience. There have been failures of some types of self-lubricated bushings attributed to contamination of sand or other particles between the bushings and the journals. These contaminants are flushed out by the periodic application of grease in grease-lubricated bushings. Consider all factors, such as the cleanliness of the water and frequency of gate operation, before making a choice.

Gasket and seals. Based on drawing recommendations and on the unit inspection, gasket materials, 0-rings, and other seals should be procured. The seal materials should be compatible for the service for which they are intended. Gaskets will be needed on flanged oil and water pipe connections, oil tubs, generator air coolers, the packing box, and other similar applications. 0-ring material is many times used as a seal on the headcover and oil tub covers. A gasket cutting kit can speed up the making of special gaskets. Silicon caulking

type gasket material can be useful during an overhaul, but only the silicon material specifically formulated for use as gaskets should be used, and it should only be used where the parts will not have to be shifted after installation. The silicon manufacturer's directions should be followed regarding the material's limitations.

Marking tags or marked bins. As parts are removed from the unit, they should be marked in some way to identify where they go and stored in a manner so that they can be conveniently located during reassembly. For small parts, such as nuts and bolts, storage bins labeled to show their contents are helpful. For large or bulky parts, such as wicket gate grease lines, tags describing what a part is and exactly where it goes are very useful. If the part itself is marked, make sure the marking pen is permanent or use an engraver to etch the part.

Welding rod or wire. If the unit inspection indicated that substantial welding repair is required, a supply of welding rod or wire should be obtained. Also, a welding procedure for the required repairs should be written and distributed to all personnel that will be involved in the welding.

Large rosebud or propane torches. During removal of the thrust block, it is important to heat it quickly so that it expands without transferring heat to the generator shaft. Several large "weed burner" type propane torches or rosebud oxyacetylene torches can be used for this purpose. As these torches are not always dependable, it is a good idea to have at least two more than are required to act as backups. These torches can also be helpful in breaking loose frozen or severely corroded parts. Large rosebud torches use a great deal of acetylene and sometimes require two acetylene bottles to be manifolded together. The supplier of the torch should be able to provide information on the acetylene requirements for a particular torch.

Hydraulic jacks. Various hydraulic jacks can be invaluable during an overhaul. Large hollow-core jacks are very useful in lowering the turbine and turbine shaft when breaking the coupling and in pulling the coupling bolts. Hydraulic wedges and hydraulic rams of various sizes are helpful in breaking loose stuck parts.

Hydraulic and pneumatic wrenches. Hydraulic-operated wrenches can save a great deal of time in removing bolts that would otherwise require the use of a slugging wrench. Their primary use on hydrounits are breaking loose and tightening the shaft coupling, bolts but on large units there may be a number of other applications. Large pneumatic impact wrenches can also greatly speed

up the disassembly and reassembly of a unit. Caution should be used in using either hydraulic or pneumatic wrenches so as not to over or under tighten bolted connections.

Magnetic based drill. A large magnetic-based drill can be especially useful during an overhaul if any components must be slightly shifted and redoweled or if there are other modifications to the equipment. Magnetic-based drills allow fairly large holes to be bored accurately and also can be used in reaming dowel holes.

Shaft packing or seals. Whenever a unit is overhauled, the compression packing of the main shaft and wicket gates should be replaced. Enough packing should be ordered to allow for errors in cutting the packing. There are a number of different types of packing available, so when choosing new packing, care should be taken to ensure that it is the correct size and type for the intended application. Be sure to take into account all the relevant conditions the packing will operate under, such as shaft size and rotational speed. Installing the wrong packing can result in excessive leakage, reduced service life, and damage to the shaft or sleeve. Where mechanical seals are used for the main shaft, a complete set of seal segments should be on hand in case any of the segments are damaged during disassembly.

Micrometers and standards. Inside and outside microm, along with a set of standards for calibration, are essential for the overhaul of a hydrounit. Micrometers are required to check diameters of main shaft bearings and journals, wicket gate bushings and journals, and other wear parts to determine if they are within tolerances. An electric micrometer may also be required for unit alignment or installation of a boring bar.

Boring bars. Even if seal ring and wicket gate bushing replacement are not planned, boring bars for both should be available just in case of an unexpected situation. Suitable boring bars should be located and shipped to the jobsite well before the overhaul. If boring is scheduled, the boring bars or accurate drawings of the boring bar should be available well before the overhaul so that any modifications, such as mounting brackets and boring anus, can be made.

Seal rings. On units with replaceable seal rings, a spare set of rings should be onsite regardless of whether or not replacement is scheduled. On units where the current seal ring design is questionable or where the rotating and stationary rings are both

stainless steel, a new design should be considered. For more information on seal ring design and material selection, refer to appendix A.

Generator air coolers. If the inspection or maintenance records indicate that the generator air coolers require repair, specifications for the repair work should be prepared. If the repair work can be accomplished by plant personnel, materials such as spare tubes and all of the tooling required for retubing should be procured.

Scaffolding. Turbine pit scaffolding to provide access to the shaft coupling and lower guide bearing, and draft tube scaffolding to provide access to the draft tube and bottom of the turbine runner, are required for any overhaul. The scaffolding must be designed to support the weight of several maintenance personnel plus components from the unit, such as bearings or the runner cone. Scaffolding should be designed, built, and installed in accordance with Reclamation Safety and Health Standards and American National Standards Institute (ANSI) Standard A10.8, "Safety Requirements for Scaffolding."

Cribbing material. Cribbing material for cribbing parts removed from the unit should be procured. Large timbers in various lengths and widths should be available to block up the parts, spread out the floor loading, and protect the floor. 'timbers should be stress graded and rated for use as cribbing. Rough lumber may not have the compressive strength for heavy components. In some cases, special jack stands may be needed. If these are required, they should be designed by an engineer competent in the field and fabricated well before they are needed.

Miscellaneous materials. A good supply of steel plate, angle iron, steel bar stock, etc., in various thicknesses and sizes should be on hand for fabricating special tools or brackets that may be required during the overhaul. There are always items that have to fabricated once the overhaul is in process, and delays can be avoided if the materials are available on site.

Ill. DISASSEMBLY

3.1 Preshutdown and preteardown readings

The purpose of preshutdown and preteardown readings are to determine the condition of the unit prior to the overhaul so necessary repairs can be made during the overhaul. Operational readings, such as vibration and temperature data, can provide a signature of the condition of the unit before teardown. The preteardown readings are also useful as reference data during reassembly. In taking the readings, it is important that all readings are consistent. For example, the north, south, east,

and west positions used for the shaft alignment readings do not necessarily have to correspond exactly with the actual directions, but the position the bearing, seal ring, and air gap readings are taken must correspond within a few degrees, with each other, and the alignment readings. Referring to the readings as downstream, upstream, right, and left may help with consistency. Preshutdown readings should include all pertinent information such as reservoir and tailrace elevations, wicket gate opening, and unit load.

Preshutdown readings. The preshutdown readings should include, but not be limited to the following:

- **Shaft runout readings**-While shaft runout readings can be measured with dial indicators, the preferred method would be to install at least one pro3dmity probe at each guide bearing elevation and record the data to a strip chart recorder, tape recorder, or some other type of data logging device. Readings should be taken at various loads from speed-no-load to full load including readings at any rough zone and with and without the field voltage at speed-no-load.

- **Bearing temperatures.-**Bearing and oil temperatures should be recorded at various loads. If a temperature recorder is part of the unit instrumentation, a recording of a normal startup showing the rate of temperature rise should be included. The unit load and wicket gate position should be noted on the recording.

- **Pressures.-**The normal operating pressure of the turbine bearing oil pumps, packing water supply, and cooling water supply should be recorded. The pressure of the thrust bearing, high-pressure lubrication system should be recorded during startup and shutdown.

- **Permanent magnet generator (PMG) voltage.-**The PMG voltage should be checked and compared to rated voltage. If the measured voltage is more than 20 percent lower than the rated voltage, the field should be remagnetized during the overhaul. *Facilities, Instructions, Standards, and Techniques (FIST), Volume 2-3, 'Mechanical Governors for Hydroelectric Units'* has a procedure for remagnetizing the rotor of a PMG in section II.

Preteardown readings. The preteardown readings should be taken after the unit is shut down and the clearance has been issued and should include, but not be limited to, the following:

- **Guide bearing and seal ring clearances**.-Clearance readings should be taken on all guide bearings at least in four quadrants. On segmented shoe guide bearings, check the clearance of each bearing shoe. Top and bottom seal ring clearance should also be taken.

- **Generator air** gap.-Air gap readings should be taken at least in four quadrants and at the top and bottom of the rotor. For better accuracy in determining the position of the rotor in the stator and for determining the shape of the stator, more readings may be required.

- **Shaft alignment readings.-** Preteardown alignment readings may be taken with or without the guide bearings in place. With the bearings in place, the bearing centers can be plotted to determine their concentricity, but the shaft itself will not be free, and the shaft's actual straightness may not be represented by readings. With the bearings and the packing removed, the shaft should be hanging free, and the readings should represent the condition of the shaft, but the operating position of the shaft and bearings will not be known. If the bearings are removed, a check of the static shaft runout should be made.

3.2 Labeling and match marking

Prior to removal, most parts should be match marked to make sure they are installed in exactly the same position from which they were removed. This is especially important for parts that can be rotated, such as thrust block keys, or for parts such as wicket gates, that can be interchanged. Many parts are marked during the original assembly. If these markings are visible and their meanings are clear, no more marks should be made. If new match marks or labels are made, the original markings should be completely removed so there is no confusion during reassembly.

3.3 Disassembly

It is important during disassembly to check the manufacturer's drawings carefully to make sure all parts are removed in the correct order and that all fasteners, piping connections, and wiring are removed. It is also important that the various crafts coordinate their activities so that there is no unanticipated delays due to the unavailability of personnel.

The list of weights and a rigging manual should be consulted often during disassembly., The weight of any part should never be "guessed," and the rigging should never be assumed to be strong enough. A part may be much heavier than it appears, and rigging, due to sling angles or other

factors, may be loaded much higher than expected. The weight of each component should also be considered when storing the parts so that the allowable floor loading is not exceeded.

The following are general procedures for the removal of some of the common parts of a hydrogenerator. The actual procedures used will probably vary depending on the design of the unit.

Permanent magnet generator. After disconnecting the wiring from the PMG terminal block, remove the mounting bolts, being careful not to lose the insulating washers and bushing. Center the crane over the PMG and lift it off using eyebolts installed in the PMG case. Store the insulating gasket between the PMG and the exciter housing with the PMG.

Exciter. After removing the brushes, wiring, and exciter housing bolts, the crane should be centered as close as possible over the exciter and the rigging hooked up to the exciter housing. To prevent contact between the exciter stator and rotor, strips of thick gasket material should be inserted in the exciter air gap, or if possible, the entire exciter rotor may be wrapped with gasket material.

Thrust block. The thrust block or thrust collar is fitted to the generator shaft with a very tight fit and requires heat to expand it for removal. Prior to removal, the unit should be jacked and blocked on the jacks so that there is no weight on the thrust block. The oil should be completely drained, and bearing housing covers and vapor seals should be removed to provide access to the block. The rigging to lift the thrust block should include turnbuckles so that the block can be kept level to prevent binding when it is lifted off the shaft. If the design allows, the rigging should be attached and adjusted before the block is heated. Some thrust block designs will not allow this, as the radial keys must be removed before the rigging can be installed. The heat should be applied quickly so that the block can expand without transferring heat to the shaft. To accomplish this, several large "weed burner" type propane torches or rosebud oxyacetylene torches should be used. Care should be taken not to heat the rigging excessively. The length of time required to heat the block will vary depending on the "tightness" of the fit on the shaft and the condition of the mating surfaces of the block and shaft. In most cases, when the block has expanded, it will drop slightly, allowing the radial keys to be removed and the block to be removed. Thrust blocks that rest on a shoulder on the shaft will not drop, and the crane must be used to apply a slight upward force on the block until it "pops" up. In these cases, a dynamometer installed in one leg of the rigging can be helpful in preventing an overload on the rigging before the block is expanded sufficiently.

Generator rotor. The generator rotor is usually the single heaviest component to be removed during an overhaul. In essentially all cases, special lifting devices and a pedestal for storage are provided. The lifting devices should be thoroughly inspected long before the rotor is removed. Large generators may require two cranes to be hooked to the lifting device. The crane operators should familiarize themselves with the use of the lifting device and signals from the designated signaler.

To uncouple the generator shaft from the turbine shaft, all of the coupling bolts except four should be removed. Before removing the final bolts, machined steel blocks should be set under the turbine runner on the support ledge to limit the amount the turbine runner and shaft have to be lowered. The shaft and runner can then be lowered using the last four bolts or by clamping the coupling with hydraulic jacks, removing the last bolts, and lowering the shaft with the jacks. The turbine runner is designed to support only the weight of the turbine shaft and the runner itself, so at no time should the weight of the generator rotor be allowed to rest on the turbine.

Plywood strips, 6 to 10 inches wide, 1/4 to 3/8 inch thick, and 8 feet long should be cut to fit in the generator air gap to prevent the rotor from contacting the stator while the rotor is being removed. Six or more maintenance personnel should be stationed around the stator with the strips inserted in the air gap moving them up and down. If the rotor gets too close to the stator, the strips will become tight, alerting the crane operators to stop and recenter the rotor.

Guide bearings. The bearing shoes of segmented shoe guide bearings can usually be lifted out of the bearing housing by one or two people once the bearing cover is removed.

The turbine bearing, which is almost always a split shell journal bearing, must be lifted out of its housing using come-a-longs or chain falls. The bearing is then set on blocks on top of the bearing housing and unbolted to split it in two so that it can be removed from the turbine shaft.

On some units, the upper and lower generator guide bearings are also split shell journal bearings. In the case of the upper guide bearing, it is usually one piece and can be simply lifted off with the crane once the excitor and bearing cover are removed. Special attention should be given to the upper guide bearing insulating gaskets to prevent breaking or misplacing any of the segments. The lower guide bearing usually must be lowered down into the turbine pit using threaded rods and nuts or come-a-longs after the oil pot is removed. The bearing is lowered to rest on top of the shaft coupling, split, and the bearing halves lowered to the scaffolding.

Wicket gate linkage. The wicket gate operating linkage consists of the servomotors, shift ring or operating ring, wicket gate links, and the wicket gate arms. Although the gate links and gate arms should, in theory, be interchangeable, they should be matchmarked to their respective wicket gate and the gates marked according to their installed position. In some units, the gate link length is adjustable to permit adjustment in the closure of the wicket gates. Care should be taken not to disturb the adjustment of these type links to reduce the amount of time required to adjust the wicket gates during reassembly. Another method of adjusting the wicket gates is through the use of eccentric pins located either in the shift ring or the gate arm end of the gate link. The position of each eccentric pin should be marked to reduce the amount of adjustment during reassembly.

Headcover. The turbine headcover, because of rust, many times can be very difficult to break loose. Before trying to lift the headcover, it should be broken loose using hydraulic jacks between the upper and lower facing plates. This will eliminate any chance of overstressing the rigging or bouncing the load with the crane.

Turbine runner and shaft. With the headeover removed, the turbine runner and shaft, in most cases, are fairly straightforward to remove. There is usually a lifting device that attaches directly to the turbine shaft, and the shaft and runner are simply lifted out of the turbine pit.

IV. INSPECTION AND REPAIR OF UNIT COMPONENTS

4.1 Bearings

Upon removal, all guide and thrust bearings should be thoroughly inspected. Minor scratches and even some deep gouges can be repaired adequately by carefully scraping the high spots from the babbitt surface. Extreme care must be taken when scraping a bearing to prevent removing too much babbitt. Also check the bond between the babbitt and the bearing shell. Because of the dovetails in the bearing shell, a guide bearing usually can operate satisfactorily with little physical bond between the babbitt and the shell, but if there is noticeable separation, it is a good idea to install the spare bearing or to have the bearing rebabbitted before the unit is reassembled. Also, when the babbitt is severely damaged by inadequate lubrication or if the inner diameter of journal bearings is beyond design tolerances, the bearing should be rebabbitted.

When it is necessary to rebabbit bearings, an American Society for Testing and Materials (ASTM) B-23, grade 2 or grade 3 tin-based babbitt should be used. Split shell journal bearings, and if possible segmented shoe guide bearings, should be rebabbitted by centrifugal casting. Thrust

bearing shoes must be poured. Regardless of the method used to rebabbit the bearings, ultrasonic testing should be performed to verify the integrity of the babbitt to steel bond and the absence of porosity. A babbitt to steel bond of no less than 85 percent should be specified.

The bearing journals and thrust runner should also be inspected for any damage. The journals should be checked for any scoring or other damage. Damage is rare, but in most cases scratches or scoring can be adequately repaired by s6ning to remove any high spots. More severe damage may require machining. The thrust runner should be checked for scoring on the bearing surface and for any fretting corrosion damage between the runner and the thrust block. If fretting corrosion is severe, check the contact area between the runner and the thrust block. If less than 70 percent, machining may be necessary. If machining is required, choose a machine shop carefully, as it is critical that the thrust runner surface be perfectly perpendicular to the shaft. Tolerances for thrust runners are usually in the 10-thousands-of-an-inch range.

4.2 Turbine runner

In most cases, the repair of cavitation damage can be accomplished much more effectively with the runner removed from the turbine pit, as the runner can be positioned for easier access. An overhaul is an excellent opportunity to restore the runner to like new condition, or in some instances, better than new condition. *FIST Volume 2-5, Turbine Repair,* describes techniques and procedures for repairing turbine runners.

4.3 Wicket gates

The wicket gate bushing and packing journals should be measured and checked to drawing tolerances. The wicket gate shaft should be checked for straightness. The top and bottom sealing surfaces should also be checked for wear or cavitation damage. The heel-to-toe seal areas should be checked for straightness and to verify that the seal surfaces are parallel to the gate shaft.

Worn or corroded journals that operate in greased bronze wicket gate bushings should be built up by welding with a 309 stainless steel and machined back to original diameters. The repair to the top and bottom sealing surfaces will depend on the damage and on the facing plate material. If the damage is obviously from misaligned or misadjusted wicket gates with no apparent galling, and the materials of the gate and facing plates are not prone to galling, weld repair with a material similar to the gate material should be sufficient. If galling is present, a galling resistant material should be used to overlay the top and bottom surfaces. If the facing plate is a bronze, a stainless steel or Nitronic 60 stainless steel weld overlay would be recommended. If the facing plates are stainless steel or steel. Nitronic 60 or nickel

aluminum bronze, C95500 should be used. If the heel-to-toe sealing surfaces require repair, these surfaces should be built up with the same or similar material as originally used unless there is galling or other problems that indicate a change in material is needed.

In performing weld repairs to the wicket gates, the following general procedures should be followed. In preparation for welding, the surface to be welded should be machined to sound material at least 0.125 inch deeper than the final dimension. Where an overlay of a dissimilar material is being used, such as bronze or stainless steel over mild steel, enough material should be removed to allow at least three weld passes to be made. This will ensure that the metal at the finished surface will be undiluted by the parent material and therefore possess the desired properties. After the welding is complete, the gates should be finish machined to the manufacturer's drawing dimensions. It is important that the finish machining be completed after all the welding is complete to allow for the correction of any distortion that may occur from the heat of welding.

4.4 Facing plates and wicket gate bushings

The top and bottom facing plates' surfaces should be checked for wear and galling. The headcover should be installed without the wicket gates. All of the headcover's mounting bolts should be installed and tightened to full torque to check the facing plates for level and parallel. While the plates should be level, it is more important that they be parallel to each other and perpendicular to the wicket gate bushings to prevent binding of the wicket gates. Parallelism can be checked by measuring the vertical distance between the plates with an inside micrometer. The plates can be checked for level using a precision level or a laser device with horizontal sweep capability. If the plates are not parallel and/or not level, the method of correction will depend on the amount the plates are off and the amount of excess material available to machine.

The easiest method of repair is to install a boring bar and machine the surfaces level and parallel, but this can only be done if there is sufficient material. If this is done, the top and bottom surfaces of the wicket gates will have to be built up to maintain the design clearances between the gates and the plates. If there is not sufficient material for machining the plates true and if the unit is designed for replaceable plates, new plates will have to be installed. Building up the replaceable plates by welding is not recommended as their relatively thin cross section can allow a great deal of distortion from welding.

Removing the old plates normally requires locating the retaining bolts, usually twist-off bolts that have been welded in place, and drilling them out. The new facing plates should have sufficient thickness to allow for machining to compensate for any unlevelness in the plates. The retaining boltholes can be drilled and counterbored according to the manufacturer's drawing, but if a drawing is not available or if there is any doubt as to

the accuracy of the drawing dimensions, the old facing plates should be used to lay out the bolt pattern. Twist-off bolts are usually used to retain the facing plates. A necked down portion of the bolt allows the hex of the bolt to twist off at predetermined torque value leaving the bolt head flush with the facing plate surface. The head is then tack welded to the plate to prevent it from backing out.

Once the new plates are installed, a boring bar with a horizontal feeding tool slide can be used to machine the plates level and parallel to each other. To achieve this, the installation and alignment of the boring bar is critical. The boring bar must be plumb and the tool slide feed perpendicular to the boring bar. After machining, the vertical distance between plates should equal the wicket gate height plus the recommended amount of clearance between the gates and the plates.

The diameter of the wicket gate bushings should be measured and compared to the drawing tolerances. When the headcover is installed to check the facing plates, the wicket gate bushings should also be checked for concentricity and for perpendicularity to the facing plates. If it was determined that the bushings are worn beyond the allowable tolerance, the bushings should be removed from the headcover and bottom ring and the bushing fits checked for concentricity and perpendicularity. Nonperpendicularity of the bushing and facing plates should have been noted during preteardown checks of the top and bottom clearances of the wicket gates. If the bushings are not perpendicular to the facing plates, the clearance measurements would indicate that the gates are operating at an angle to the plates. Concentricity can be checked by hanging a single tight wire through the center of the bushings, or bushing fits, and measuring from the wire to the bushing or fit surfaces. If the bushings or bushing fits are not concentric or not perpendicular to the facing plates, the bushings should be replaced and line bored. Procedures for line boring are discussed in section V, entitled, "Field Machining Procedures." If it is determined that the fits for the bushings are concentric, new bushings can be installed without line boring. When this is done, the bushing inner diameter must be slightly larger than required to compensate for the reduction in diameter that occurs when the bushing is pressed in place. This can take some experimentation to achieve the correct installed inner diameter. To facilitate the installation of the bushings, they should be shrunk by packing in dry ice or storing in a freezer overnight.

In some cases, the top two bushings or bushing fits will be within tolerance for plumb and perpendicularity, but the bottom bushing will not. In this event, the top two bushings are replaced without line boring, and the bottom bushing is line bored concentric to the top two. This simplifies the installation and line boring procedures significantly.

The bushing and pins of the wicket gate linkage should be checked against drawing tolerances. The bushings on the linkage can usually just be pressed in place already finish machined. As with the wicket gate

bushings, the inner diameter will have to be slightly larger than required to compensate for the reduction in diameter that occurs when the bushings are pressed in place.

The bearing plates on the operating ring should be checked for excessive wear and replaced if necessary. The grease grooves of the originals should be duplicated on the new bearing plates.

4.5 Packing box and shaft sleeve

Many times the packing box will be severely corroded. If the metal loss is significant in the packing box bore, the packing will have to be overcompressed in order to fill the bore. This will lead to shortened packing life and excessive wear of the shaft packing sleeve. If the packing box is still structurally sound, the interior bore of the box can be built up with a properly applied epoxy coating. If the corrosion has reached the point that the box has been weakened significantly, some other method of repair or complete replacement may be required. Once the surfaces have been repaired, the packing box should be painted.

The turbine shaft packing sleeve is usually constructed in two pieces so that it can be replaced when worn. In some cases, the sleeve can be built up by welding and machined back to the drawing dimensions. Welding on the packing sleeve must be accomplished with a minimum amount of heat input to prevent inducing stress and distorting the sleeve. Another alternative is to flame spray the sleeve with a wear-resistant material and machine it back to original dimensions. The coating used in flame spraying must be chosen carefully and the proper procedure followed to ensure proper bonding to the parent material.

4.6 Servomotors

In some instances, due to contaminants in the oil or misalignment, the servomotors for the wicket gates will require repair. The most common types of damage are scoring in the cylinder and scoring on the piston rods. Scored cylinders must be bored out and honed to remove the scoring. New piston rings then must be fabricated to match the new inner diameter of the cylinder. To restore the piston to cylinder clearance, bronze sleeves or bands of phenolic material can be installed on the piston.

The first step in repairing scoring on the piston rod is to turn down the rod by machining to remove the scoring. The rod must then be built up to allow grinding to the final diameter. If mildly scored, electroplating with industrial hard chromium may be used to restore the rod diameter. If the scoring was deep, it may be necessary to build the rod up by welding or other means to restore it to its original diameter.

4.7 Cooling coils and generator air coolers

The bearing cooling coils and generator air coolers should be thoroughly inspected for leaks, corrosion, and mineral buildup. The end of the air coolers should be removed to allow the inspection of the tube sheet and the connection of the tubes. Leaking tubes should be replaced. If a significant number of tubes are leaking or if their general condition is questionable, the entire cooler should be retubed. After retubing, the cooler should be hydrostatically tested at a pressure of at least 110 percent of the working pressure to check for leaks.

The bearing cooling coils should be thoroughly inspected and hydrostatically tested. Due to corrosion and weakening of joints due to years of vibration, it is sometimes more economical to replace the coolers rather than trying to repair them. If it is determined that it is feasible to repair the coils, a hydrostatic test should be performed after the repair to insure the repair was successful and that no new leaks have developed.

The piping to the air coolers and cooling coils should be checked for corrosion and mineral buildup and replaced if necessary.

4.8 Exciter

The condition of collector ring and commutator of the exciter rotor should be checked for roundness and evidence of wear or arcing. The groove on the commutator should be thoroughly cleaned of carbon dust or other contaminants. If necessary, the collector rings should be machined in a lathe to restore their surface finish and roundness.

4.9 Generator structure

With the unit disassembled, it is possible to perform a thorough inspection of components not normally accessible. The upper and lower bridges should be checked for cracked welds or other signs of damage. The torque on the stator frame bolts should be checked and the dowels checked to make sure they haven't backed out. The rotor spider should be checked for cracks with special attention given to where the arms connect to the hub and the rotor ring. The brake ring should be checked for uneven wearing, cracks, and evidence of excessive heating.

4.10 Generator brakes

The generator brakes should be disassembled for inspection. If there is corrosion or scoring in the cylinder, it should be rebored or honed, depending on the extent of damage, and if necessary, a new piston fabricated and installed. Leather packing should be replaced with a fluorocarbon or similar material.

V. FIELD MACHINING PROCEDURES

5.1 Seal rings

One of the most common field machining operations performed on hydroelectric units is the boring of the stationary seal rings. In most cases, the operation involves boring new seal rings, but it may also include the machining of the discharge ring, throat ring, and/or headcover to accept the new rings.

The boring bar must be precisely set up so that the rings are bored concentric to each other and to the unit guide bearings and generator stator. To accomplish this, the desired center of the unit with reference to the seal rings must be determined. To find the unit's center, the upper bridge and headcover should be installed after all the rotating parts have been removed. A single tight wire should be hung through the unit and reference measurements taken from the stator, the turbine bearing housing, the packing box bore, and to trammel points in the draft tube. The trammel points may be bolts welded to the draft tube liner with the heads machined to match an inside micrometer or any marked point where measurements can be repeated exactly.

If the generator guide bearings are not adjustable, the lower bridge should also be installed and reference measurements taken from the lower and upper bridges. Once the measurements have been taken and the centers plotted, it can be determined where the center of the seal rings should be. Ideally, the generator stator, all of the guide bearings, and the seal rings should be perfectly concentric, but some compromise within the recommended tolerances may be required.

In determining the center for boring the seal rings, several things should be taken into consideration. The center of the turbine bearing housing should be within the allowable tolerances for center of the stator (refer to appendix C). Although it is not a simple job, the turbine bearing housing, in many cases, can be moved to center and redoweled. If the seal rings must be bored significantly off center to make them concentric to the unit center, there must be sufficient "meat" to allow boring to the required diameter. In some cases, the packing box is not movable and will be the limiting factor in how far the seal ring centers can be moved. If the calculations show that after moving the seal ring centers as far as they can be moved, the stator will still be excessively off center, it may be necessary to move the stator. As moving the stator can be difficult, it should only be attempted if absolutely necessary and after careful planning.

Once the center for the seal rings has been determined, it can be helpful to move the plumb wire to the center point and take the final reference measurements. While this is not necessary, it will simplify the calculations required during the installation of the boring bar. The boring bar is positioned and plumbed by centering it at the reference points at

the turbine bearing housing (or head cover if the turbine bearing housing is removed) and the trammel points in the draft tube. The installation procedure will vary with boring bar design, but usually the boring bar thrust bearing and a guide bearing are mounted on the turbine bearing housing or directly to the headcover. Another guide bearing is usually mounted in a spider type frame welded to the draft tube liner. The guide bearings usually have some adjustment to allow moving the bar to center. When the boring bar is centered and its guide bearings locked in place, the boring arm and tool slide can be installed. The motion of the tool slide should be perfectly parallel to the bar for vertical cuts and perpendicular to the bar for horizontal cuts. If necessary, the tool slide should be shimmed where it mounts to the boring arm to make it perfectly parallel or perpendicular.

The boring bar drive speed should be adjustable, using either an electric motor with solid state frequency controls or a hydraulic system with some means of varying flow. The cutting speed for boxing will depend on the type of material being machined, the diameter of the ring, the depth of cut, and the feed rate of the tool slide. *The Machinery Handbook* and other machining reference books list a range of recommended cutting speeds based on these factors. The optimum speed, cut depth, and feed rate will have to be determined onsite through experimentation.

5.2 Facing plates

As discussed in the previous section, it is sometimes necessary to machine the facing plates in order to make them true and parallel to each other. A boring bar with a tool slide with a horizontal feed can be used to machine the facing plates' surfaces. Because of the interrupted cut caused by the holes in the facing plates for the wicket gate bushings, the cutting tool will see a great deal of shock. The cutting speed and feed in most cases must be reduced to prevent breaking the tool bit.

5.3 Wicket gate bushing line boring

When it is necessary to line bore the wicket gate bushings, the installation of the boring bar is critical. The bar must be made plumb, positioned at the correct radial distance from the unit center, and in the correct angular position with reference to the other gates. Whatever procedure is used to accomplish this, it must be repeated 16 to 24 times depending on the number of wicket gates.

In most cases, centering the boring bar in the intermediate bushing will be within the tolerance for the radial distance from the unit center and the distance between gates. The radial distance should be verified by measuring the distance from a single plumb wire hung through the center of the unit to the boring bar. The distance between gates should be measured between the boring bar and a wire hung through the last hole bored. The first hole bored will be the reference.

The most critical step in installing the boring bar is making the bar plumb. If the bar is not installed plumb, there will be gaps between the wicket gate sealing surfaces, and in severe cases, the top and bottom surfaces of the gates may bind against the facing plates. There are several procedures for plumbing the boring bar. The best one for a particular unit will depend on the size and design.

Plumb wires can be used to plumb the bar. Ideally, four wires hung 90 degrees apart would be used to allow for a check in the accuracy of the readings. Realistically, there is rarely room for four wires. Normally, a wire hung through the center of the unit, which is also used for checking the radial position of the bar, and wires hung in the holes on either side of the hole being bored are used. Readings should be taken several times to verify their accuracy.

If the bushing diameter is large enough, another method can be used with plumb wires. This method uses a single wire hung through the bushing bores. The wire is centered in the intermediate bushing, and reference measurements are taken from the bushings to the wire. These reference measurements can then be used to position the boring bar in the same position as the wire. Since the wire hangs plumb, the boring bar will be plumb.

If the facing plates are within tolerances for parallelism but not levelness, the wicket gates should be bored perpendicular to the facing plates and not plumb. Some fixture or jig will have to be fabricated to make the boring bar perpendicular to the plates. If the facing plate surfaces are smooth, a dial indicator attached to the boring bar can be used to position the bar.

If it was determined that the top two bushings were within tolerance for plumb and perpendicularity but the bottom bushing was not, the boring bar can be set up by centering it in the top two bushings. Plumb, radial position, and distance between gates still should be checked by plumb wires or other means.

Appendix C lists tolerances for wicket gate installation. These standards are only intended to be used as a guide since variables in the construction of the unit may make larger or smaller tolerances acceptable.

5.4 Redoweling

Units with nonadjustable guide bearings require the precise placement of the bearing brackets. Bearing brackets and other components that need to be held in an exact position many times use dowel pins. The boltholes on these components are usually oversized to allow the parts to be shifted slightly during the alignment process. The dowels have a very tight fit to prevent the components from shifting once the part is positioned.

The dowel pins may be hardened or unhardened steel and may be straight or tapered. Tapered pins are easier to remove than straight pins. Hardened pins are normally used where strength, shock, or wear are factors. If the components are held together with threaded fasteners, and the pins will see little shear stress or wear, unhardened dowel pins are sufficient.

When doweled components are moved during the alignment process following the overhaul of a unit, redoweling is necessary. Depending on the location and size of the dowels and the amount of available room, it will be necessary to either relocate the dowels or bore the e2dsting holes to accept a larger dowel. If the dowels are relocated on components subject to varying temperatures, such as the generator stator, care should be taken to install the dowel so that they do not impede differential thermal expansion.

A magnetic-based drill should be used to bore the hole for the dowel. To ensure a tight fit, the hole is always drilled undersized and reamed to match the dowel pin. The reaming can be accomplished using the magnetic-based drill and a chucking reamer, or it can be done with a hand reamer and a wrench. If the drill is used, care should be taken to properly align the reamer and to choose the right cutting speed to prevent oversized or bellmouth holes and to achieve a good finish. If the components were only moved a few thousands of an inch, expansion reamers can sometimes be used to ream the e2dsting hole to use a slightly oversized dowel.

5.5 Coupling boltholes

When new turbine runners are installed as part of the overhaul, it is usually necessary to rebore the turbine shaft to turbine runner coupling boltholes. On rare occasions, the coupling bolts on the generator-turbine shaft coupling may gall upon removal to the point reboring is required. The normal procedure is to temporarily bolt the shaft to the runner or the shafts together using four bolts. The bolts should be tightened sufficiently to ensure the mating surfaces are making full contact. 'right wires or laser alignment equipment is then used to check for dogleg and offset. Offset can be corrected by shifting the shaft, but dogleg requires remachining the shaft or the runner mating face. When it is determined that the shaft is correctly positioned, the holes are bored slightly oversized from the original diameter to accept new coupling bolts.

The boring equipment used will depend on the size of the hole being bored. In some cases, a magnetic-based drill can be used with a boring bar. If a magnetic-based drill is used, a bearing for the boring bar should be mounted at the bottom of the hole to add additional support. Cylinder boring machines for engines can also be used in some instances. These machines are designed to bore the cylinders of large diesel or gasoline engines but can be used for boring coupling boltholes with some modifications. On large holes, a boring bar similar to that used on wicket

gates can be used. Once the hole is bored, a cylinder hone is used to smooth the surface and achieve a good surface finish. A great deal of care should be taken when using a hone to prevent making the hole bellmouthed or out-of-round.

VI. REASSEMBLY

6.1 Torque or stretch of bolts

In order for a bolted joint to function as intended, the bolts must be tightened uniformly and to the proper preload. The most common method of preloading bolts is with a torque wrench. There are numerous tables available with suggested torque values for various sizes and grades of bolts. While these tables can be very helpful, it should be noted that the torque required to achieve a desired preload on a bolt can vary a great deal depending on the condition of the threads and the type of lubricant, if any, used. If the threads are cleaned up with a thread chaser or tap or die, and the lubricant specified on the torque table is used, in most cases, a torque wrench is adequate for tightening bolted joints.

A more accurate method of measuring the preload of a bolt is to measure the amount the bolt stretches as the nut is tightened. In many cases, this is not possible, but on shaft coupling bolts, it is relatively easy to measure the length with a micrometer.- Unless otherwise specified by the manufacturer, as a rule of thumb, the coupling bolts should be stretched to one-half of their yield strength. Equation 1 can be used to determine the amount of stretch, in inches, required to achieve a preload of one-half of the yield strength.

$$\delta = \frac{LS_y}{2E}$$

Where:

δ = *ELONGATION OF BOLT (in)*
L = *LENGTH OF BOLT (in)*
S_y = *YIELD STRENGTH OF BOLT* $\left(\frac{lbs}{in^2}\right)$
E = *MODULUS OF ELASTICITY* $\left(\frac{lbs}{in^2}\right)$

Equation 1

There are several methods of stretching the coupling bolts. One method uses a sledge hammer and slugging wrench. This method is very labor intensive and time consuming. Usually one person holds the wrench while another person hits it with the sledge hammer. The bolt must be

measured after every few hits to determine the stretch. With experience, the person swinging the sledge hammer can usually get a feel for when the stretch on the bolt is right.

The use of hydraulically operated wrenches is becoming more common. This system uses a high pressure, hydraulic cylinder to drive the wrench. By observing the system pressure, the torque on the bolt can be determined and used as a guide in stretching the bolt. The preload of the bolt should still be checked by measuring the stretch with a micrometer. Hydraulic wrenches allow much closer control of the bolt stretch as well as being much less strenuous.

Another method of stretching bolts is with the use of bolt heaters. The bolt is measured while still cold and then the heater is inserted in an axial hole through the center of the bolt. As the bolt is heated, it expands, and while it is still hot, the nuts are tightened to retain the expansion. The final stretch is measured with a micrometer after the bolt has cooled. This method will usually take some trial and error to achieve the desired stretch in the bolt.

6.2 Unit alignment

It is critical that the generator and turbine shaft be properly plumbed and the guide bearings be made plumb and concentric. The exact procedure will vary depending on the design of the thrust and the guide bearings. *FIST Volume* 2-1*, Alignment of Vertical Shaft Hydro Units,* describes in detail the alignment procedures for the various type of bearings as well as tolerances for the alignment.

Once the shaft alignment is determined to be acceptable, preparation for installing the guide bearings can begin. Since the alignment procedures call for plumbing the center of runout and not the shaft, the shaft will not be perfectly plumb and will probably not be in the desired running position with reference to the bearing centers. This will not be a problem if the guide bearings are all nonadjustable and the bearing housings have already been made concentric and plumb as part of the alignment process. In this case, the shaft is moved to center in the upper generator guide and turbine guide bearing housings and the bearings installed.

If the upper and lower guide bearings are the adjustable segmented shoe type, the shaft will have to be positioned so that it can be used as a reference for setting the clearances on the bearing segments. To make the bearing centers all concentric, the shaft must be perfectly plumb. This can be accomplished by installing the turbine bearing and shimming the shaft to center in the turbine bearing. Plumb readings, are then taken to determine the position of the shaft. From these plumb readings, the top of the shaft can be moved to make it plumb. The upper and lower guide bearing segments can then be installed and set using the shaft as a reference.

Setting the clearances on segmented shoe bearings can be a challenge. Most designs allow the segments to pivot around the adjustment bolt. Since the segments pivot, obtaining accurate clearance readings with a feeler gauge can be very difficult. When taking readings with a feeler gauge, it is essential that the segment be held level and tight against the adjusting bolt. When inserted, the feeler gauge should extend all the way through the bearing to prevent obtaining a false high reading at the top of the segment when the bottom is tight against the shaft. It is also helpful to measure the clearance on either side of the pivot point at the same time to prevent the shoe from pivoting to one side or the other.

Another method of setting the clearance is with a dial indicator on the adjusting bolt. The bolt is turned in to make the bearing tight against the shaft, and the dial indicator is set up on the head of the bolt and zeroed. The bolt is then backed out the amount of the desired clearance and the lock nut tightened. The lock nut must be tightened with care; if it is overtightened, it can actually stretch the adjusting bolt to the point that the clearance is significantly reduced. As the bolt is stretched between the locknut and the shoe, there will be no indication on the dial indicator. If the dial indicator method is used, the clearance still should be verified with feeler gauges.

6.3 Wicket gate adjustment

The heel-to-toe clearance between wicket gates must be minimal to prevent excessive leakage once the unit is watered up. Turnbuckles or eccentric adjustments are provided in the wicket gate linkage to adjust the position of the gates and the clearances between them. Procedures for adjusting the gates are found in appendix D.

The squeeze on the gates should also be adjusted. The squeeze is the amount the servomotors travel after the gates contact each other. The squeeze takes up the slack in the gate operating mechanism and holds the gates shut when the spiral case is watered up. The squeeze must be adjusted so that each servomotor moves the same amount to prevent distorting the operating ring. Part III, Section B, of *FIST Volume 2-3,* "Mechanical Governors For Hydroelectric Units" has a procedure for adjusting the squeeze on the wicket gates.

6.4 Gaskets and packing

The gaskets should be cut prior to reassembly using the old gaskets as a pattern if possible. The mating surfaces of the gasketed joint should be thoroughly cleaned and checked for any large nicks, dents or gouges, or any other surface imperfections that would prevent the gasket from sealing. The gasket material used must be compatible with the fluid being sealed and should be as thin as possible while being thick enough to seal. The manufacturer's recommendation should be used if available or the old gasket can be used as a guide, keeping in mind that the old gasket is probably somewhat deformed by

compression. The bolts should be tightened to uniformly compress the gasket. This means going from one side to the other around the joint. Gasketed joints should be retorqued after the unit has been in operation for 1 or 2 days.

Compression packing on wicket gate shafts and the turbine shaft should be installed with the joints staggered 90 degrees apart. It is sometimes helpful to lubricate the packing prior to installation. The packing manufacturer should be consulted for recommendations for a lubricant and for any special instructions that may be required for the type of packing being used. With all of the packing and the lantern ring, if so equipped, in place, the packing gland should be installed finger tight. The wicket gate packing can be somewhat tighter because of the limited rotational movement of the wicket gates.

There should be generous leakage upon the initial startup after the installation of new turbine shaft packing. The packing gland should be tightened evenly and in small steps until the leakage is reduced sufficiently. The gland should be tightened at 15- to 30-minute intervals to allow the packing time to break in. The temperature of the water leaking from the packing should be cool or lukewarm, never hot. If the water is hot, back off the packing gland.

Mechanical seals are sometimes used instead of compression packing on the turbine shaft. The seal consists of sealing segments, usually made of carbon, held against the shaft by spring tension and lubricated by a thin film of water. A grease zerk is usually provided to lubricate the seals prior to startup following an overhaul or lengthy outage.

Since mechanical seals are precisely made and rely on very tight tolerances in order to operate successfully, a great deal of care must be taken during the installation. Just a small amount of dirt or other contaminants on the polished sealing surfaces can allow leakage past the seal and reduce the seal's life. The seal segments are also usually very brittle and are easily broken. A spare set of segments should be on hand in the event any should break.

6.5 Governor

If possible, the governor should be tested and adjusted prior to startup using a PMG simulator. The PMG simulator provides a three-phase alternating current at a voltage and frequency that matches the output of the PMG. The simulator drives the ballhead motor at normal synchronous speed which makes the governor operate as if the unit was online. If the PMG simulator is available, these tests can be performed as soon as the servomotor and wicket gates are operational. The tests are described in *FIST Volume* 2-3, "Mechanical Governors for Hydroelectric Units."

Regardless of whether or not the PMG simulator is available, the) full rate wicket gate timing must be set before the unit is watered up. As mentioned previously, the wicket gate time should be obtained from a hydraulic transient study or test reports.

VII. STARTUP

7.1 Final inspection

Once all the items on the checklist, other than operational tests and adjustments, are completed and just prior to starting the unit for the first time following the overhaul, a final inspection of the unit should be made. Some of the items listed below will have been checked previously, but because of potential damage to the machine, they should be checked again. This inspection should include, but not be limited to, the following:

Visual inspection of generator housing and spiral case. A very thorough inspection of the generator housing and spiral case should be made to check for any bolts, nuts, tools, etc. In the generator housing, check on top of rotor arms, under fan covers, or any place that a part or tool could possibly have been left. Once these areas have been inspected and verified to be clean, no one should be allowed back in. If it is necessary for someone to go back into these areas, they should remove everything from their pockets and make a list of every tool that is taken in so that they can verify nothing is left inside when they are finished.

Bearing lubricant levels. All bearing lubricant levels should be checked just prior to startup. If the lubricant level is indicated by a sight glass, the valve to the sight glass should be checked to make sure it is open and the level in the sight glass is accurate.

Cooling water supplies. The flow and pressure of the cooling water to the generator and bearing coolers should be checked to make sure it is adequate. The packing box cooling water supply should also be checked.

Clearances. Clearances between stationary and rotating parts should be checked. Bearing covers, vapor guards, rotor fan blades, etc., should be checked for adequate clearance.

Bearing and PMG insulation. The upper guide bearing, the thrust bearing, and the PMG are usually insulated from the frame to prevent damage that could occur from circulating currents passing through them. The insulation should be checked with an ohmmeter prior to startup following the procedure in *FIST Volume* 3-11, "Generator Thrust Bearing Insulation and Oil Film Resistance."

Oil or water leaks. With full pressure and flow, check threaded and flanged joints of the various water lines to the unit for leaks. Check oil piping and bearing oil tubs for leaks at joints.

7.2 Initial startup

When the unit checkout has been completed and the clearance for the overhaul released, the unit can be watered up for startup. Maintenance personnel should be stationed with two-way radios at strategic locations near the unit to listen and watch for anything unusual when the unit is started. The wicket gates should be opened just enough to start the unit turning and then shut. This should be done several times to check for "rubs" or other problems. If no problems are noted, the wicket gates should be opened to bring the unit to 100-percent speed. If at any point any of the observers notice any unusual noise or other problems, they should notify the operator to immediately shut the unit down. If no problems are noted, the unit should continue to operate at speed-no-load until bearing temperatures stabilize.

If the governor was not adjusted before startup, it is possible that the unit will "hunt." If this is the case, gradually close the governor dashpot needle until the hunting stops. The governor can be adjusted for optimum response after the bearing temperatures stabilize.

7.3 Operational readings

Once it is determined that the unit can be operated with no problems, the following readings should be taken and compared to the preteardown readings. It is very likely that, depending on what modifications have been made to the unit, a great deal of other testing besides these readings will be required. These readings are suggested only as basic indication of the unit's condition. Various index or acceptance tests, as well as numerous tests of the electrical equipment, will be required following any uprate or major overhaul.

Bearing heat run. With the unit running at speed-no-load, the bearing metal and oil temperatures should be recorded until the temperatures stabilize. If a data logger is not available, the temperatures should be recorded manually every 5 minutes for the first 30 minutes of operation and every 15 minutes after that until the temperatures stabilize. After the unit is brought online, again monitor temperatures as the unit is loaded.

Shaft runout readings. The runout readings can be taken with dial indicators but are much more meaningful if taken by proximity probes. Readings should be taken at various loads from speed-no-load to full load. Special attention should be given to the runout at any rough zones the turbine may have. If proximity probes are used, the signal should be recorded with a strip chart recorder so that the wave form of the runout can be analyzed. A normal runout

pattern will be a sine wave with a time period corresponding to the rotational speed. If problems are encountered, such as extremely high runout magnitude or a hot bearing, further analysis should be performed. If two proximity probes are mounted 90 degrees apart at each elevation, their output can be hooked up to a two-channel oscilloscope to plot the actual runout orbit pattern. This can be helpful in detecting a rub in the bearing. A spectrum analyzer is also useful when troubleshooting a vibration problem. The spectrum analyzer breaks down the signal from the proximity probes into its component frequencies. The runout readings taken should also be compared to the readings taken before the unit was shut down for the overhaul.

Load rejection tests. If a hydraulic transient study was performed to determine the correct wicket gate timing, either because the unit was uprated or the original data was lost, load rejection tests should be performed to verify the findings of the study. The study should provide predicted spiral case pressure versus time graphs and unit overspeed versus time graphs for the forebay and tailrace elevations at the time of the tests. The wicket gate timing should have been set to the value recommended by the hydraulic transient study before the unit was watered up.

Load rejection tests should be performed at lower loads before performing a full load rejection. Immediately following a test at a lower load, the test data should be studied to make sure that a rejection at the next higher load can be performed without exceeding design limits. If, from the test data, it appears that the pressure could possibly exceed the design pressure at full load, the wicket gate timing should be slowed down before the full load rejection test is performed. If pressure is significantly lower than the hydraulic transient study and the overspeed higher, the wicket gate timing can be made faster.

If the unit being tested is equipped with a pressure regulator or an automatic bypass valve, several load rejections should be done from not more than 15-percent gate to verify the wicket gate timing. While the wicket gate timing still should be set with the unit unwatered, some regulator designs are such that the timing can only be accurately tested during an actual load rejection.

Immediately prior to the test, the following data should be recorded:

- Gate position
- Load
- Forebay elevation
- Tailrace elevation
- Spiral case pressure

The following should be monitored and recorded by a strip chart recorder during a load rejection test:

Breaker position.-A reference signal to determine exactly when the breaker opens can be helpful. This can be a signal from the generator current transformer or a breaker contact that opens or closes with the main breaker.

Gate position.-A string transducer or other position transducer should be connected to one of the servomotors to monitor wicket gate position. The strip chart recorder should be calibrated from 100- to 0-percent gate.

Unit speed.-Unit speed should be recorded with a tachometer or frequency transducer with sufficient range to measure the speed from zero to the predicted maximum speed.

Spiral case pressure.-Spiral case pressure should be monitored by a pressure transducer connected to a valved tap in the spiral case mandoor. If a tap is not available in the mandoor, the transducer can be installed directly on the piezometer ring just upstream from the penstock. Installation on a long line or a line with a bourdon tube type gauge or sensor can lead to false data.

Surge tank pressure.-A pressure transducer should be mounted at the base of the surge tank to monitor water elevation in the tank. Under no circumstances should the water overtop the tank.

Generator voltage.-A voltage transducer connected to the generator potential transformer should be used to monitor generator voltage.

Pressure regulator.-If a pressure regulator or automatic bypass valve is present, its position should be monitored by a string transducer or other position transducers.

Shaft runout.-Proximity probes should be installed at each of the guide bearing elevations to monitor shaft runout during the load rejection tests.

After the test, the following data should be recorded:

- Wicket gate timing
- Maximum shaft speed
- Maximum spiral case pressure
- Maximum generator voltage
- Maximum surge tank pressure or elevation
- Regulator valve closure time

APPENDICES

Appendix A

SEAL RING DESIGN AND SPECIFICATIONS

SEAL RING DESIGN AND SPECIFICATIONS

INTRODUCTION

The purpose of seal rings or wearing rings, as they are also called, is to provide a renewable seal or leakage joint between a turbine runner and its casing. The small clearance between the stationary and rotating rings limits the flow of water from the high pressure areas to low pressure areas of the turbine. As the clearance increases over time, the amount of water flowing through the seal rings increases, decreasing the efficiency of the turbine. As seal ring clearances increase to 200 percent of the manufacturer's design clearance, the efficiency can decrease as much as 2 percent. Prior to a scheduled overhaul, the seal ring clearances and the design of the seal rings should be analyzed. If the seal ring clearance has increased significantly or if the seal ring design is questionable, replacement should be considered.

Seal ring design

Ideally, seal rings should last 20 years or more. This type of longevity is not always possible, but to achieve the longest life possible, the seal rings must be constructed of materials that are resistant to wear and corrosion. Wear can occur as a result of cavitation or abrasive erosion. Abrasive erosion caused by silt or other suspended particles in the water is usually not a concern in turbines that receive their water from deep reservoirs, but it can be a problem in pump-turbines or turbines that receive their water from a canal or other shallow waterway. Cavitation erosion is dependent on the amount of head of the unit, the seal ring clearance, and the hydraulic characteristics of the unit. The occurrence of corrosion will depend on the seal ring material and the quality of the water.

The galling resistance between the rotating and stationary ring materials must also be considered. Under normal operating conditions, the rings should never touch. However, in some circumstances such as the failure of the turbine guide bearing, failure of a seal ring, or during unit alignment, they can come in contact. If contact is made between materials that are prone to galling, the rings can be severely damaged, and in extreme cases, the rings may seize.

Over the years, seal ring designs have varied. In some plants, cast steel rings that were integral parts of the turbine runner and casing were used. While cast steel is not prone to galling, it is susceptible to cavitation erosion, abrasive erosion, and corrosion. The cast steel performed acceptably in most circumstances, but as material technology improved, other materials were tried in an attempt to achieve longer life.

In the 1950's and 1960's, the Bureau of Reclamation commonly specified hardened 400 series martensitic stainless steel for both the rotating and stationary seal rings. These rings were much more resistant to corrosion and cavitation erosion than the cast steel rings. The rings were heat treated to different hardness values, apparently with the idea that it would prevent galling in the event of contact between the rings. The rotating ring was a shrink fit on the runner, and the stationary rings consisted of dovetail segments held in place with soft copper caulking in a dovetail groove. This design was not successful as the copper would erode over time allowing the segments to come loose. The stainless steel against stainless steel, even with the different

hardness values, was still likely to gall. In one instance, the upper and lower ring both seized when the stationary segments came loose.

Another problem encountered with martensitic stainless steel is its susceptibility to stress corrosion cracking when not heat treated properly. Tempering 410 stainless steel between 700 "Fahrenheit (^{o}F) and 1,050 ^{o}F results in decreased corrosion resistance. Rotating rings failed at several facilities due to specifying a hardness that required tempering at 900 ^{o}F.

To solve the galling problem, dissimilar metals should be specified. As the result of laboratory testing, austenitic stainless steel and aluminum bronze were determined as the best combination of materials for seal zings. In the tests, these materials were found to be not only resistant to galling when brought into moving contact, but both materials proved to be more cavitation resistant than the martensitic stainless steel.

To replace the dovetailed segments of the stationary ring, aluminum bronze segments rolled from bar stock and held in place with radial fasteners were used. This design also proved unsuccessful. Rings of this design failed in a relatively short time after installation. The rolled bar stock tended to lose its rolled dimension, creating a clearance between the ring and its mating surface. The clearance allowed the ring to move, creating a vibration that led to fatigue cracking. The rolling process itself caused cracks to form on the outside diameter of the rings. Other factors that may have contributed to the failure were overtorquing the fasteners, flaws in the fasteners, and stress concentration caused by the radial boltholes.

Current seal ring design calls for making the rings in one piece whenever possible. The preferred method of manufacture is by centrifugal casting. Centrifugal casting forces the metal outward while the lighter impurities remain on the inside diameter. The impurities are removed by machining. When the rings are very large, centrifugal casting may not be possible, and sand casting or ring rolled forging may be used. Ring rolled forging is a process that produces a large-diameter seamless ling by rolling a heated, smaller-diameter ring with a thick cross section, between two rollers. Rotating rings can also be fabricated by rolling bar stock and welding the ends, but casting is preferable. When new stainless steel turbine runners are installed the rotating rings are specified to be an integral part of the runner.

The single piece rings are designed to be a shrink fit and usually don't require fasteners. If the stationary ring has to be installed in sections, each section is cast, or the ring is cast in one piece and cut by wire electrodischarge machining (EDM) process. EDM is specified because the width of cut by normal sawing techniques would be greater than 0.020 inch where the width of a wire EDM cut is less than 0.010 inch. If fasteners are required, they should be made from Nitronic 60 stainless steel. Nitronic 60, unlike most stainless steels, is resistant to galling as well as being resistant to cavitation erosion and corrosion.

REFERENCES

Christenson, D.J., and Duncan, W. H., "Turbine and Large Pump Seal Rings," Water Operation and Maintenance Bulletin No. 159, March 1992.

Peabody, S.C., United States Bureau of Reclamation, Wearing Ring Design, Preliminary Report, November 1991.

SAMPLE SPECIFICATIONS

I. INTRODUCTION

The following specifications specify stainless steel for the rotating ring and nickel aluminum bronze for the stationary ring. In special circumstances, it may be desirable to make the rotating ring bronze and the stationary stainless steel. Centrifugal cast, single piece rings are preferable, but on large rings, sand casting or ring rolled forging may be required. These specifications are only provided as a guide. Specifications for new seal rings should be issued only after adequate research and analysis has been performed.

II GENERAL REQUIREMENTS

A. Stationary seal ring. Each seal ring shall be cast as one piece from nickel aluminum bronze, copper alloy C95500 or copper alloy C95800. The seal rings shall be cast to nominal size by sand casting in accordance with American Society for Testing Materials (ASTM) B148 or centrifugally casting in accordance with ASTM B27l, or they shall be cast to a smaller diameter with a thicker cross section and ring rolled forged to the required larger diameter. Rings cast from C95500 shall be annealed and tempered. Rings cast from C95800 shall be annealed. The heat treatment procedure of the casting shall be submitted for approval and shall include the initial annealing temperature range and cooling rate and the tempering temperature range and cooling rate if applicable. If the contractor elects to ring roll forge after casting, the procedure must be submitted for approval.

If the zing is to be supplied in sections, each section shall be cast or the ring may be cast in one piece, finish machined, and cut into sections using the wire EDM process or other method that removes no more than 0.010 inch of material per cut.

B. Rotating seal rings. Each seal -ring shall be constructed of stainless steel of the chromium nickel-alloy type, conforming to ASTM A 743 grade CF-8 or CF10SMnN (Nitronic 60) if cast, or conforming to ASTM A 167 type 304L if fabricated. If cast, the seal rings shall be cast to nominal size, or they shall be cast to a smaller diameter with a thicker cross section and ring rolled forged to the required larger diameter. Fabricated rings shall be rolled and welded with not more than two weld seams per ring. Fabricated rings shall be stress relieved, and the stress relief procedure shall be submitted for approval. Cast rings shall be heat treated, and the heat-treating procedure shall be submitted for approval. If the contractor elects to ring roll forge after casting, the procedure must be submitted for approval.

III. WELDING

Major defects in the castings may be repaired by welding with the consent of the contracting officer. If the rings are fabricated from more than one piece, welding procedures and drawings identifying the welds shall be submitted for approval. All welds shall be 100-percent nondestructively inspected by radiographic, dye penetrant, or other nondestructive means. These inspections shall be at the expense of the contractor. The qualification of welding procedures, welders, and welding operators shall conform to section IX of the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code.

IV. LADLE ANALYSIS AND MECHANICAL PROPERTIES

Certificates showing the results of the ladle analysis and mechanical properties tests shall be submitted for approval. Test coupons for mechanical properties shall be worked and heat treated in the same manner as the seal rings and shall be destructively tested to determine tensile strength, yield strength, and Brinell hardness. Mechanical properties shall meet the specified values in the above ASTM codes.

V. FINISH OF SEAL RINGS

The finished rings shall be free from voids, cracks, and surface defects. The finished surfaces of the seal rings shall not exceed 125-microinches maximum surface roughness in accordance with American National Standards Institute (ANSI) 46.1.

VI. FINAL INSPECTION

Inspection of the seal rings will be made by the contracting officer or the contracting officer’s representative at the point of manufacture prior to preparation for shipment. A manufacturer's inspection report with final dimensions of each ring shall be submitted to the contracting officer for approval before shipment.

VII. SHIPPING

The seal rings shall be sufficiently supported during shipment to assure a rigid retention of their shape. Shipping will be the responsibility of the contractor.

Appendix B

SAMPLE CALCULATION
FOR SEAL RING INSTALLATION

SAMPLE CALCULATION FOR SEAL RING INSTALLATION

By Ernie Bachman

The following is a sample calculation for determining the dimensions for replacement seal rings. It is a general example showing the formulas and assumptions made when calculating the stress and fit of seal rings. Refer to figure Bl for dimensions. Only the calculations for the top seal rings are shown as they would be essentially the same for the bottom rings.

SYMBOLS AND ABBREVIATIONS

D_t = *TURBINE RUNNER OUTER DIAMETER* = 160 *in*

D_{rr} = *INNER DIAMETER OF ROTATING SEAL RING* (*in*)

D_{sr} = *OUTER DIAMETER OF STATIONARY SEAL RING* (*in*)

D_{hc} = *INNER DIAMETER OF HEADCOVER* = 166.5 *in*

N = *UNIT RUNAWAY SPEED* = 410 $\frac{rev}{min}$

g = *ACCELERATION DUE TO GRAVITY* = 386 $\frac{in}{sec^2}$

σ_{sf} = *STRESS FROM SHRINK FIT* $\left(\frac{lbs}{in^2}\right)$

σ_{cf} = *STRESS FROM CENTRIFUGAL FORCE* $\left(\frac{lbs}{in^2}\right)$

σ = *TOTAL STRESS* $\left(\frac{lbs}{in^2}\right)$

V = *VELOCITY* $\left(\frac{in}{sec}\right)$

ϵ = *STRAIN* $\left(\frac{in}{in}\right)$

δ_{sf} = *CHANGE IN DIAMETER DUE TO SHRINK FIT* (*in*)

δ_t = *TOTAL CHANGE IN DIAMETER REQUIRED FOR INSTALLATION* (*in*)

MECHANICAL PROPERTIES

SEAL RING MATERIAL = UNS J92600 (CF-8) AUSTENITIC STAINLESS STEEL

S_t = *TENSILE STRENGTH* = 77,000 $\frac{lbs}{in^2}$

S_y = *YIELD STRENGTH* (0.2% *offset*) = 37,000 $\frac{lbs}{in^2}$

ρ = *DENSITY* = 0.280 $\frac{lbs}{in^3}$

α = *COEFFICIENT OF THERMAL EXPANSION* = 10×10^{-6} $\frac{in}{in\ °F}$

E = *MODULUS OF ELASTICITY* = 28.0×10^6 $\frac{lbs}{in^2}$

ROTATING RING

Step 1. Determine inner diameter of rotating seal ring. The stress induced in the seal ring by the shrink fit (i.e., the difference between the inner diameter of the seal zing the outer diameter of the turbine runner) in most cases should not be more than one-third of yield strength of ring material. The desired unit deformation, or strain, is calculated based on one-third of the yield strength. The amount of shrink fit is then determined by multiplying the strain by the diameter of the runner. This value is subtracted from the diameter of the runner to obtain the inner diameter of the seal zing.

$$\sigma_{sf} = S_y/3 = 37{,}000/3 = 12{,}333\ \frac{lbs}{in^2}$$

$$\epsilon = \sigma_{sf}/E = 12{,}333/28.0\times10^6 = 0.00044\ \frac{in}{in}$$

$$\delta_{sf} = D_t\epsilon = (160.0)(0.00044) = 0.70\ in$$

$$D_x = 160.0 - 0.070 = 159.930\ in$$

Step 2. Determine stress in ring caused by centrifugal force. The stress in the ring caused by centrifugal force will be maximum at runaway speed. Compare this value to the shrink fit stress. If the stress caused by the centrifugal force is greater than the shrink fit stress, the ring could become loose on the runner.

$$D_c = DIAMETER\ OF\ CENTER\ OF\ RING = 161.5\ in$$

$$V = N\pi D_c/60 = (410)(3.1415)(161.5)/60 = 3467\ \frac{in}{sec}$$

$$\sigma_{cf} = \rho V^2/g = (0.283)(3467)^2/386 = 8{,}813\ \frac{lbs}{in^2}$$

Step 3. Determine temperature required for installation. The ring must be expanded by heating for installation. The tongue of the tongue and groove fit of the ring must be considered in the calculations. The total amount the ring must be expanded must include the shrink fit amount, twice the thickness of the tongue on the ring, plus the clearance required for installation.

$$\delta_t = \delta_{sf} + 2(TONGUE) + CLEARANCE = 0.07 + 2(0.125) + 0.125 = 0.445\ in$$

$$\Delta T = \delta_t/\alpha D_{rr} = 0.445/(10\times10^{-6})(159.930) = 278\ ^\circ F \qquad (6)$$

$$Assume\ 70\ ^\circ F\ Ambient\quad Final\ Temperature = 70 + 278 = 348\ ^\circ F$$

STATIONARY RING

MECHANICAL PROPERTIES

SEAL RING MATERIAL = UNS C95500 NICKEL ALUMINUM BRONZE

S_t = ***TENSILE STRENGTH*** = 105,000 $\frac{lbs}{in^2}$

S_y = ***YIELD STRENGTH*** = 40,000 $\frac{lbs}{in^2}$

ρ = ***DENSITY*** = 0.269 $\frac{lbs}{in^3}$

α = ***COEFFICIENT OF THERMAL EXPANSION*** = 9.0×10^{-6} $\frac{in}{in\ °F}$

E = ***MODULUS OF ELASTICITY*** = 16.0×10^{6} $\frac{lbs}{in^2}$

Step 1. Determine outer diameter of stationary seal ring. The top stationary seal ring is a shrink fit in the headcover. The amount of interference between the ring and the headcover should be sufficient to prevent the ring from becoming loose when the unit is watered up. The stress in the zing should be checked, but the limiting factor on the amount of interference will be the required installation temperature. The required installation temperature should not be lower than -109 °F, the temperature of dry ice. Lower temperatures are attainable with other cooling mediums such as liquid nitrogen, but this is not practical with large rings. A strain of 0.0005 inch per inch should provide a fit that is sufficiently tight and attainable with dry ice.

$$\delta_{sf} = D_{hc}\epsilon = (166.5)(0.0005) = 0.0835\ in$$

$$D_{sr} = 166.5 + 0.0835 = 166.5835\ in$$

Step 2. Determine stress in ring caused by shrink fit.

$$\sigma = \epsilon E = (0.0005)(16.0 \times 10^6) = 8{,}000\ \frac{lbs}{in^2}$$

Step 3. Check effect of watering up. Assuming a worse case of unit being dry and at a temperature of 70 °F and being watered up suddenly with 40 °F water, determine whether ring will remain tight.

$$\delta_t = \Delta T \alpha D_{sr} = (30)(9\times10^{-6})(166.5835) = 0.045\ in$$

$\delta_t < \delta_{sf}$ $\quad\therefore$ ***Ring will remain tight during startup.***

Step 4. Determine required temperature for installation of ring. Verify that installation temperature is above -109 °F.

$$\delta = \delta_{sf} + CLEARANCE = 0.0835 + 0.125 = 0.2085\ in$$

$$\Delta T = \delta / \alpha D_{sr} = (0.0835)/(9\times10^{-6})(166.5835) = 139\ °F$$

ASSUME AMBIENT OF 70 °F

REQUIRED TEMPERATURE = 70 - 139 = -69 °F

-69 > -109 ∴ *SHRINK FIT IS OK*

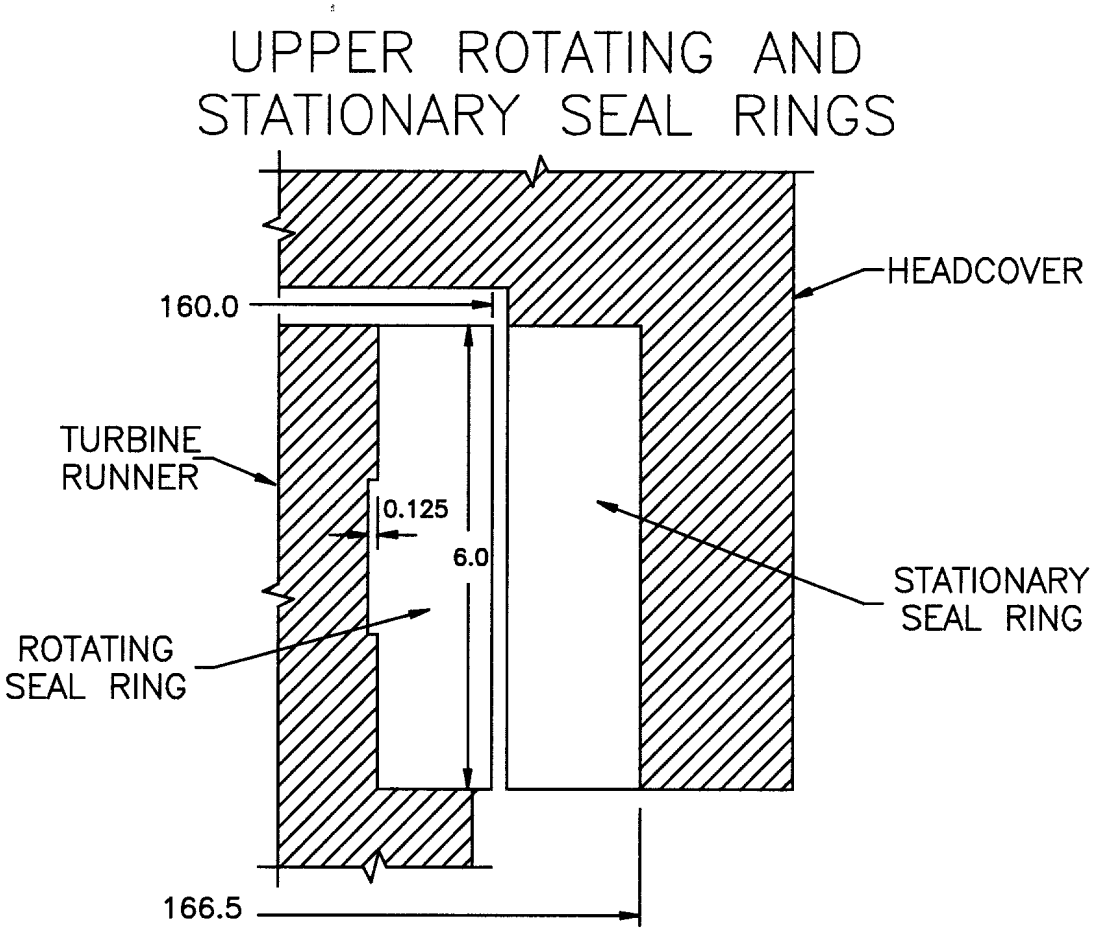


Figure B1

Appendix C

TOLERANCES FOR HYDROUNIT ASSEMBLY

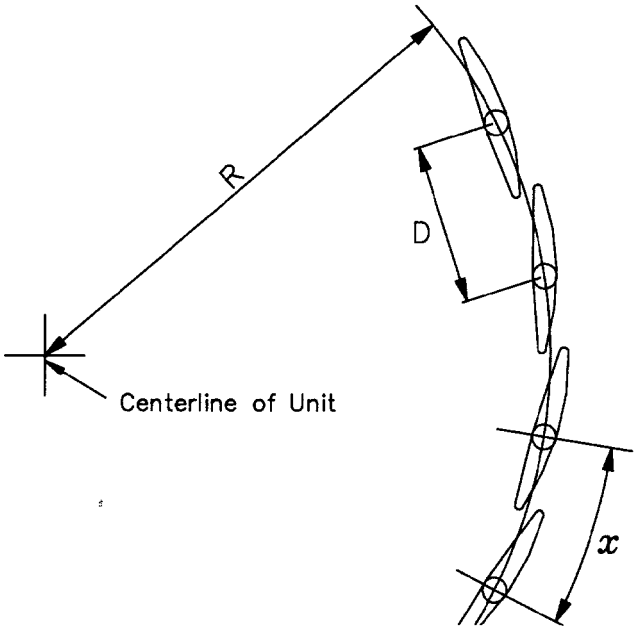
Tolerances for hydrounit assembly '
(vertical units)

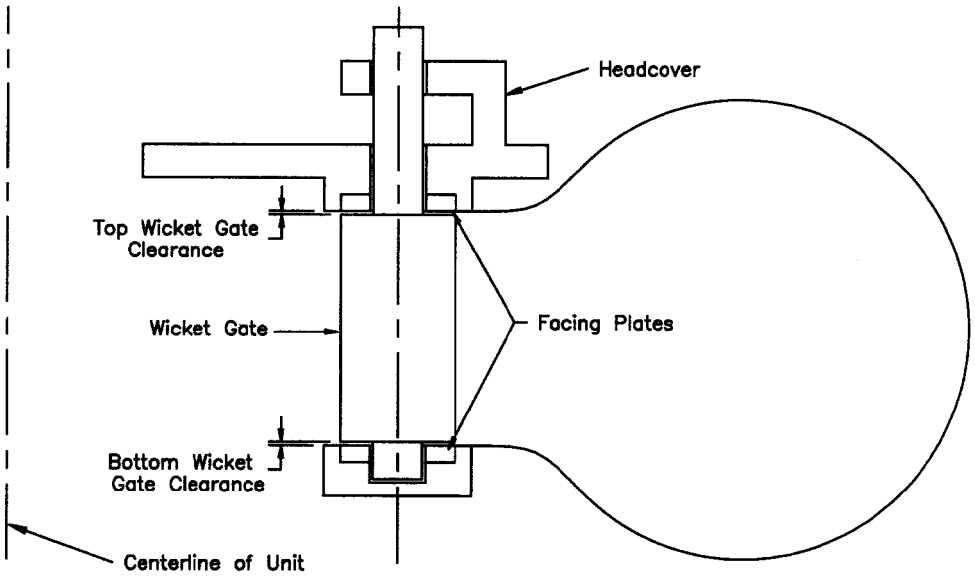
Measurement	Tolerance
Stator air gap	± 5% of nominal design air gap
Stator concentricity (Relative to turbine guide bearing)	± 5% of nominal design air gap
Upper generator guide bearing concentricity (Relative to turbine and lower generator guide bearing)	± 20% diametrical bearing clearance
Lower generator guide bearing concentricity (Relative to turbine and upper generator guide bearing)	± 20% diametrical bearing clearance
Seal ring concentricity (Relative to turbine guide bearing and each other)	± 10% diametrical seal ring clearance
Circularity of stator	± 5% of nominal design air gap
Circularity of rotor	± 5% of nominal design air gap
Stator vertically (Relative to plumb)	± 5% of nominal design air gap
Rotor vertically (Relative to generator shaft)	± 5% of nominal design air gap
Static shaft runout (Orbit diameter)	0.002 inch multiplied by the length of the shaft from the thrust bearing to the point of runout measurement divided by the diameter of the thrust runner. AR measurements in inches.
Plumb of center of shaft runout	0.000025 multiplied by the length of the shaft from the highest plumb reading to the lowest plumb reading.
Distance from wicket gate to unit center (R - figure Cl)	± 0.0002 X R
Distance between wicket gates (D - figure Cl)	± 0.0001 X D
Plumb of wicket gates'	20% of minimum diametxical wicket gate bushing clearance
Parallehsm of facing plates	20% of total (top + bottom) wicket gate clearance
Levelness of facing plateS2	20% of total (top + bottom) wicket gate clearance

1 These tolerances are intended to be used when manufacturer's tolerances are not available. Always consult equipment manufacturer first ff possible. This table is based on the table "Bureau of Reclamation Plumb and Ahgrunent Standards for Vertical Shaft Hydro Units," by Bill Duncan, May 24, 1991.

2 Plumb of wicket gate and levelness of facing plates can be outside of these tolerances as long as the facing plates do meet the criteria for parallelism and the gates are within 20 percent of the minimum diametrical wicket gate bushing clearance of being perpendicular to the facing plates.

Arrangement of Wicket Gates





R = Distance Between Wicket Gate Centerline and Unit Centerline

x = Angle Between Wicket Gates

D = Distance Between Wicket Gates = $2R \sin\frac{x}{2}$

Figure C1

Appendix D

WICKET GATE
ADJUSTMENT PROCEDURES

WICKET GATE ADJUSTMENT

When reassembling a unit following an overhaul, it is very important that the heel to toe clearance between wicket gates be uniform and tight to ensure a good seal when the unit is watered up and to evenly distribute the force from the servomotors. Turnbuckles or eccentrics in the wicket gate linkage are provided to adjust the individual gates.

A ratcheting hoist or "come-a-long" and sling are frequently used to make the initial adjustment to the gates. **Extreme caution must be used when using this procedure to prevent overloading the sling or the hoist. The sling used must have a rating higher than the hoist, and the hoist must have some type of overload indication.** With the gates and the headcover installed but prior to attaching the linkage between the gate arms and the shift ling, a sling is looped around the outside of the wicket gates and attached to the hoist. As the hoist is tightened, the sling draws the wicket gates closed. With the sling still tight, the turnbuckles or eccentrics are adjusted so that the gate linkage can be connected.

Sometimes no further adjustment is required, but in many instances, there will be gaps between the gates after the sling is released. If there are gaps, the first thing to determine is whether the gap is even from the top to the bottom of the gate. If the gates are actually touching at the top with a gap at the bottom or vice versa, the gate seal areas are not parallel to the gate shafts or the gates are not parallel to one another. In either case, there is little that can be done with the unit assembled. A determination must be made as to whether the gaps are acceptable. The amount of gap that is acceptable will depend on the unit and the number of gates with gaps. A high head unit will require tighter tolerances than a low head unit. The "squeeze" provided by the servomotors can take up some of the gap, but this will unevenly distribute the pressure to the gates and can, in severe cases, cause failure of the shear pins.

If there are gaps that are even top to bottom, the first step in eliminating these gaps is to consolidate all the gaps to one gap. The first step in accomplishing this is to disconnect all of the wicket gate linkage so that each gate, is free to move independently. One gate is then chosen to be a "master" gate, and it is opened slightly (i.e. less than 0.020 inch). Next the heel or the toe of the next gate, depending on the geometry of the wicket gate, is adjusted to just contact the master gate. Each of the following gates are adjusted in order until there is one gap between the last gate and the master gate or between the last gate and the next to last gate. This gap is removed by closing the master gate or the last gate, depending on where the gap is, and then adjusting the rest of the gates in sequence until there are no gaps.

Dial indicators set up on the gate arms can facilitate the adjustment process. When adjusting the gates, the dial indicators can be used to determine when the gates touch without having someone in the spiral case. The dial indicator will indicate movement of the "stationary" gate when the gate being adjusted just makes contact.

Two procedures for wicket gate adjustment are listed below. The procedure used will depend on the geometry of the wicket gates. The distance from the contact points or seal areas of the gates to the center of the gate shaft should be checked on the turbine

manufacturer's wicket gate drawings. Figure Dl shows two typical wicket gate plan outlines. On wicket gate A, the distance from the heel contact point to gate shaft is longer than the distance from the toe contact point to the gate shaft. On wicket gate B, the opposite is true. Because of these differences, any movement initiated at the heel will be proportionally more or less at the toe. In the case of gate A, the movement at the toe would 13/16 of the movement at the heel. In a similar fashion, any movement initiated at the toe contact point will be amplified at the heel. When adjusting wicket gates with a geometry similar to gate A, it is important to initiate the adjustment at the heel of the gate and proceed in the gate adjustment opposite in direction of the runner rotation. The adjustment of wicket gates similar to Gate B should start with the toe, and continue in the same direction as runner rotation. In this way, the amount each gate is affected by the adjustment of the first gate is gradually reduced. For example, if the heel of gate A was moved 0.010 inch and the gates were adjusted going opposite the direction of runner rotation, the movement of the toe of twentieth or last gate would be appro3dmately 0.0002 inch. If the adjustment proceeded in the direction on runner rotation, a 0.010-inch movement at the toe of the master gate would cause the heel of the final gate to move 0.630 inch. When studying the drawings to determine which gate type a particular unit has, it is important to use the distance to the contact points and not the total length of the gate.

Wicket Gate A

(Distance from heel contact point to gate shaft centerline is longer than the distance from the toe contact point to the gate shaft centerline. See figures Dl and D2.)

1. All adjustments are made with the unit unwatered. Move the servomotor and gate operating linkage to the full pressure, zero gate (squeeze) position.

2. Bleed the air from the governor accumulator tank to provide zero pressure on the servomotors.

3. Disconnect aR wicket gate linkage.so that gates are free to move independently.

4. Select a "master" wicket gate. Open gate slightly (less than 0.020 inch).

5. Moving in the direction **opposite** of runner rotation go two gates down from the master gate and open this gate slightly. This allows the gate adjacent to the master gate to be moved. Adjust the gate adjacent to the master gate until the heel contacts the toe of the master gate. Take care not to move the master gate.

6. Continue adjusting each gate in sequence in the direction opposite of runner rotation, adjusting the heel of the gate to contact the toe of the previous one. It will be necessary in most cases to slightly open the gate ahead of the one to be adjusted to allow it to move.

7. After making a complete rotation of the gates, there should be no clearances between gates except between the heel of the master gate (gate 1 - figure D2) and the toe of the last gate (20) or between the heel of the last gate (20) and the toe of the next

to last gate (19). Slightly open the gate ahead of the clearance (gate 2 if the clearance is between 1 and 20, or gate 1 if the clearance is between 19 and 20) and move the heel of gate at the clearance to contact the toe of the adjacent gate. Repeat step 6 until all clearances are acceptable.

8. Verify that the servomotor is still in the zero gate position and move if necessary. Loop a wire rope sling around the gates and draw tight with a ratcheting hoist to hold gates while wicket gate linkage is attached. **Extreme caution must be used to prevent overloading the sling or the hoist. The sling used must have a rating higher than the hoist, and the hoist must have some type of overload indication.** Attach wicket gate linkage and adjust to hold gates in position. After all of the linkage has been connected, remove the sling, repressurize the system, move the gates through their full travel several times, and check clearances.

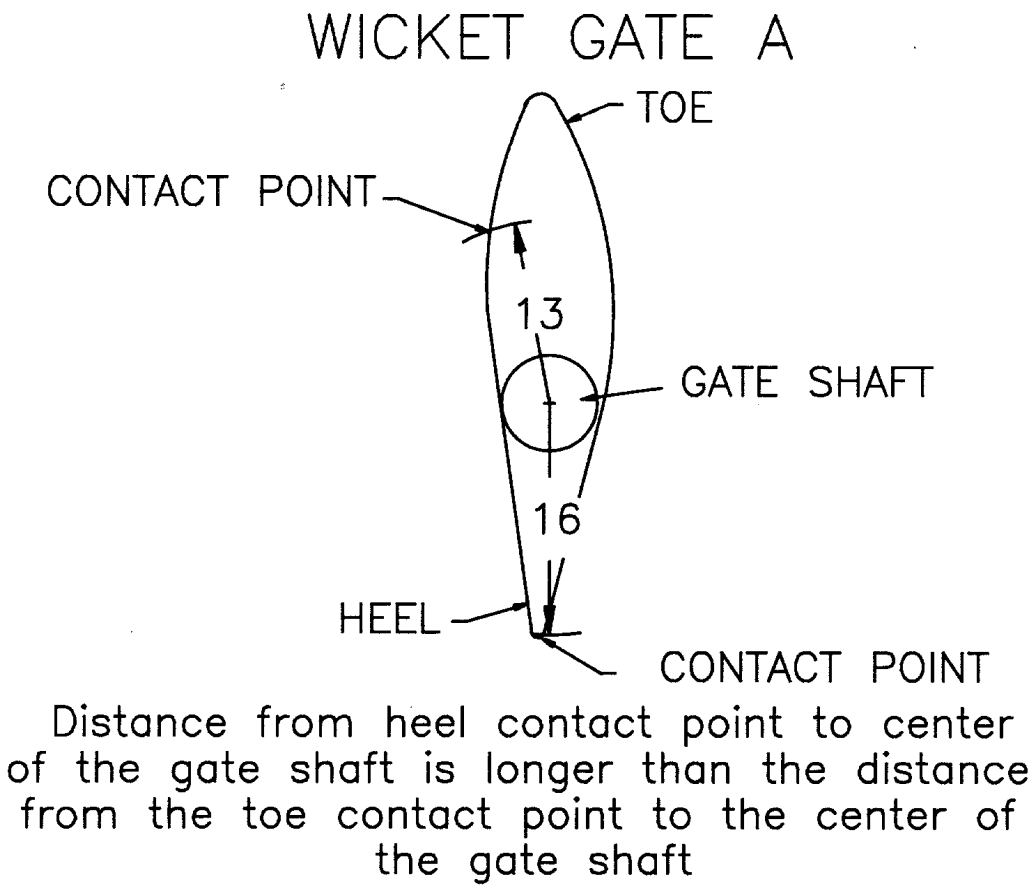
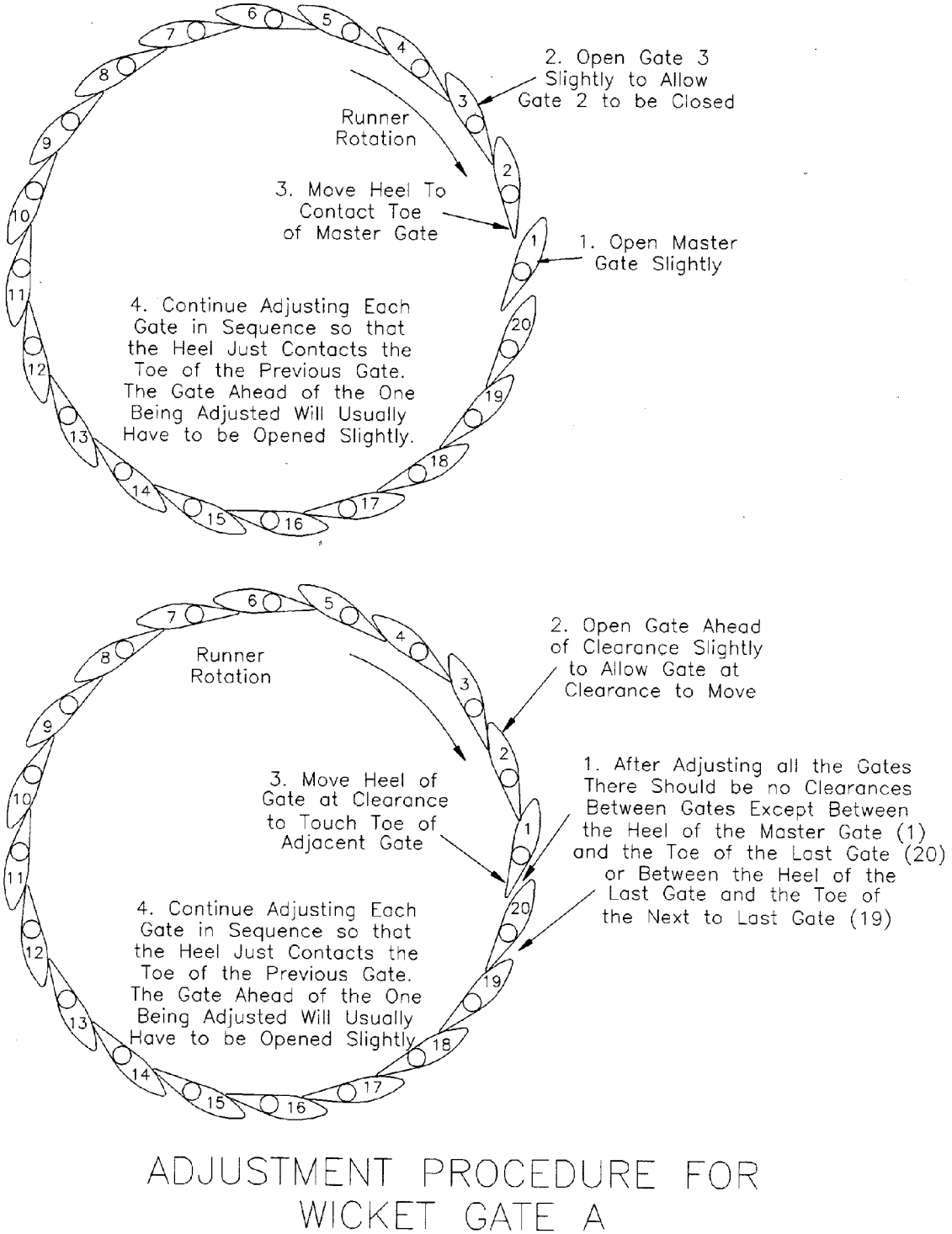

WICKET GATE A
TOE
CONTACT POINT
13
GATE SHAFT
16
HEEL
CONTACT POINT
Distance from heel contact point to center of the gate shaft is longer than the distance from the toe contact point to the center of the gate shaft

Figure Dl


2. Open Gate 3 Slightly to Allow Gate 2 to be Closed
Runner Rotation
3. Move Heel To Contact Toe of Master Gate
1. Open Master Gate Slightly
4. Continue Adjusting Each Gate in Sequence so that the Heel Just Contacts the Toe of the Previous Gate. The Gate Ahead of the One Being Adjusted Will Usually Have to be Opened Slightly.
2. Open Gate Ahead of Clearance Slightly to Allow Gate at Clearance to Move
Runner Rotation
3. Move Heel of Gate at Clearance to Touch Toe of Adjacent Gate
1. After Adjusting all the Gates There Should be no Clearances Between Gates Except Between the Heel of the Master Gate (1) and the Toe of the Last Gate (20) or Between the Heel of the Last Gate and the Toe of the Next to Last Gate (19)
4. Continue Adjusting Each Gate in Sequence so that the Heel Just Contacts the Toe of the Previous Gate. The Gate Ahead of the One Being Adjusted Will Usually Have to be Opened Slightly.

ADJUSTMENT PROCEDURE FOR WICKET GATE A

Figure D2

Wicket Gate B

(Distance from toe contact point to gate shaft centerline is longer than the distance from the heel contact point to the gate shaft centerline. See figures D3 and D4.)

1. All adjustments are made with the unit unwatered. Move the servomotor and gate operating linkage to the full pressure closed (squeeze) position.

2. Bleed the air from the govemor accumulator tank to provide zero pressure on the servomotors. The servomotor indicator should indicate zero gate position.

3. Disconnect all wicket gate linkage so that gates are free to move independently.

4. Select a "master" wicket gate. Open gate shghtly (less than 0.020 inch).

5. Moving in the direction of runner rotation go two gates down from the master gate and open this gate slightly. This allows the gate adjacent to the master gate to be moved. Adjust the gate adjacent to the master gate until the toe contacts the heel of the master gate. Take care not to move the master gate.

6. Continue adjusting each gate in sequence in the direction of runner rotation, adjusting the toe of the gate to contact the heel of the previous one. It will be necessary in most cases to slightly open the gate ahead of the one to be adjusted to allow it to move.

7. After making a complete rotation of the gates, there should be no clearances between gates except between the toe of the master gate (gate 1 - figure D4) and the heel of the last gate (20) or between the toe of the last gate (20) and the heel of the next to last gate (19). Slightly open the gate ahead of the clearance (gate 2 if the clearance is between 1 and 20, or gate 1 if the clearance is between 19 and 20) and move the toe of gate at the clearance to contact the heel of the adjacent gate. Repeat step 6 until all clearances are acceptable.

8. Verify that the servomotor is still in the zero gate position and move if necessary. Loop a wire rope sling around the gates and draw tight with a ratcheting hoist to hold gates while wicket gate linkage is attached. **Extreme caution must be used to prevent overloading the sling or the hoist. The sling used must have a rating higher than the hoist, and the hoist must have some type of overload indication.** Attach wicket gate linkage and adjust to hold gates in position. After all of the linkage has been connected, remove the sling, repressurize the system, move the gates through their full travel several times, and check clearances.

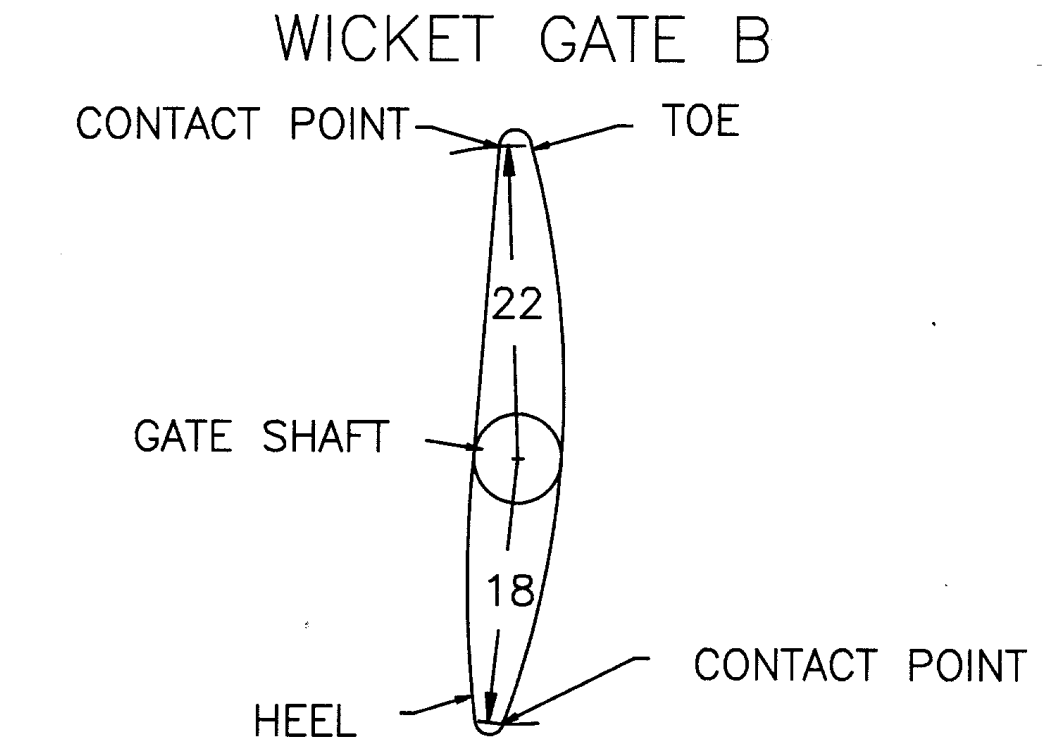
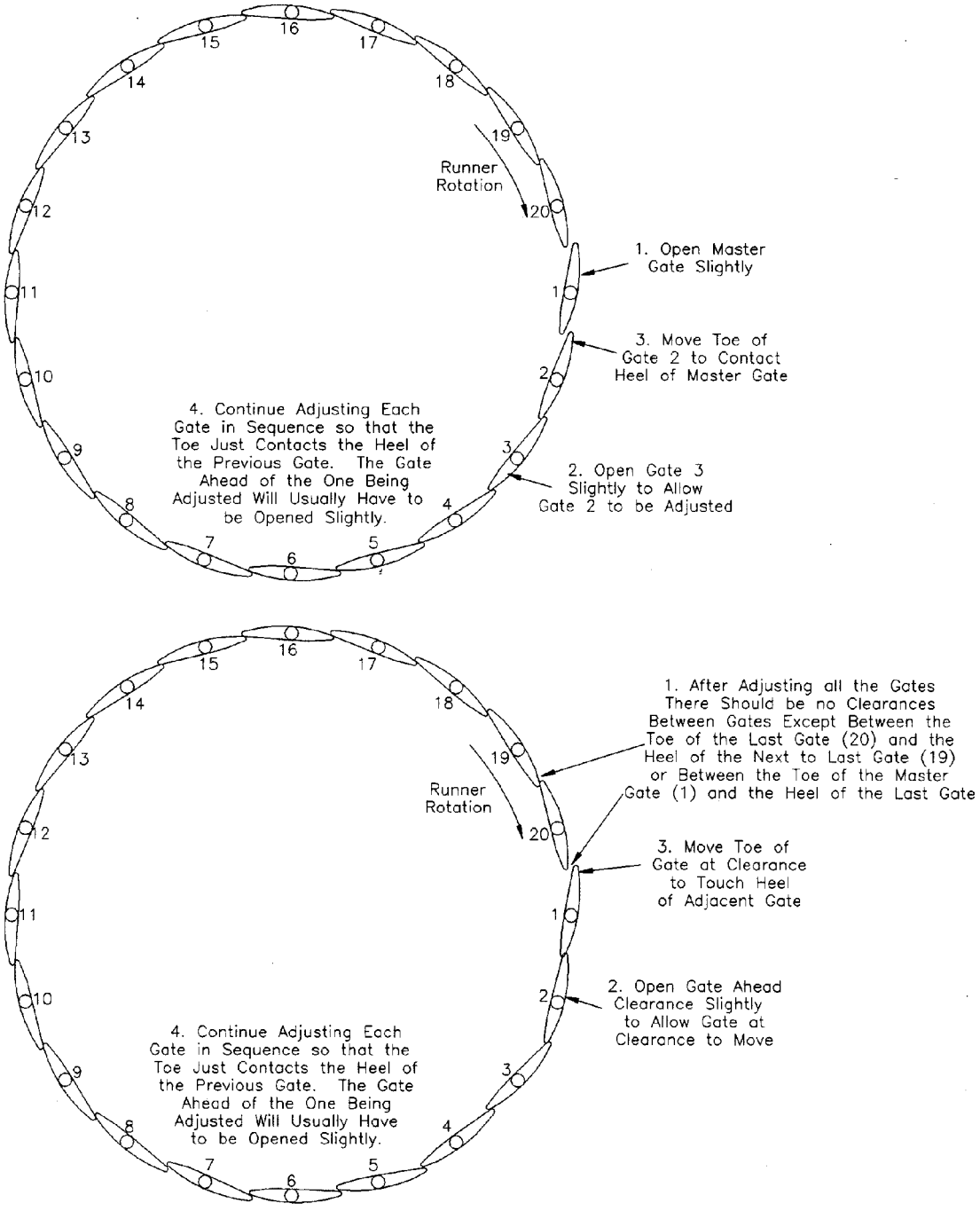

WICKET GATE B
CONTACT POINT
TOE
22
GATE SHAFT
18
CONTACT POINT
HEEL
Distance from toe contact point to center of the gate shaft is longer than the distance from the heel contact point to the center of the gate shaft

Figure D3


Runner Rotation
1. Open Master Gate Slightly
3. Move Toe of Gate 2 to Contact Heel of Master Gate
2. Open Gate 3 Slightly to Allow Gate 2 to be Adjusted
4. Continue Adjusting Each Gate in Sequence so that the Toe Just Contacts the Heel of the Previous Gate. The Gate Ahead of the One Being Adjusted Will Usually Have to be Opened Slightly.
1. After Adjusting all the Gates There Should be no Clearances Between Gates Except Between the Toe of the Last Gate (20) and the Heel of the Next to Last Gate (19) or Between the Toe of the Master Gate (1) and the Heel of the Last Gate
3. Move Toe of Gate at Clearance to Touch Heel of Adjacent Gate
2. Open Gate Ahead Clearance Slightly to Allow Gate at Clearance to Move
4. Continue Adjusting Each Gate in Sequence so that the Toe Just Contacts the Heel of the Previous Gate. The Gate Ahead of the One Being Adjusted Will Usually Have to be Opened Slightly.

ADJUSTMENT PROCEDURE FOR
WICKET GATE B

Figure D4

MISSION STATEMENTS

The mission of the Department of the Interior is to protect and provide access to our Nation's natural and cultural heritage and honor our trust responsibilities to tribes.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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